

UCRL-6473
Controlled Thermonuclear
Processes, UC-20
TID-4500 (16th Ed.)

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Livermore, California

Contract No. W-7405-eng-48

ANNOTATED BIBLIOGRAPHY OF THEORIES OF
THE EQUATION OF STATE OF IONIZED GASES AND
STRONG ELECTROLYTE SOLUTIONS

Stephen G. Brush
Carl J. Wensrich

August 8, 1961

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Contents

Abstract	v
Introductory Notes	1
Abbreviations	3
Bibliography	3
Bibliographies on Related Subjects	61
Subject Index	66

Annotated Bibliography of Theories of the Equation of State
of Ionized Gases and Strong Electrolyte Solutions*

Stephen G. Brush and Carl J. Wensrich

Lawrence Radiation Laboratory, University of California
Livermore, California

August 8, 1961

ABSTRACT

The bibliography lists 297 references on the equation of state of ionized gases and electrolyte solutions, including calculations of closely related quantities such as free energy, partition functions, osmotic pressure, activity coefficients, and equilibrium compositions of partially ionized systems. A subject index and a supplementary list of 42 bibliographies on plasma physics and similar topics are included.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

Annotated Bibliography of Theories of the Equation of State
of Ionized Gases and Strong Electrolyte Solutions

Stephen G. Brush and Carl J. Wensrich

Lawrence Radiation Laboratory, University of California
Livermore, California

INTRODUCTORY NOTES

We have collected together in this bibliography theoretical investigations pertaining to two different physical systems -- ionized gases and electrolyte solutions -- which can be approximately described by the same mathematical model. While our subject might be considered part of "plasma physics," it was found that none of the existing bibliographies of plasma physics included more than a few of the relevant papers, the early work on ionic solutions being generally ignored. Since in most cases it was not possible to decide from the title or even the abstract of a paper whether it included theoretical work on the equation of state of ionized systems, it has been necessary to look up the reference itself whenever possible, and of course there is no assurance that our list is complete. For the same reason, we have tried to include notes on each item sufficient to show its relevance to our subject and its connection with other work; in some cases this purpose can be accomplished by a brief quotation from the author's abstract, and occasionally the title itself is informative enough. The length of the commentary does not therefore bear any necessary relation to our opinion as to the value of the paper.

The theoretical similarity between electrolyte solutions and ionized gases stems from the concept that dissolved substances often behave like gases; in aqueous solutions the water molecules appear to have the sole function of encouraging ionization by reducing the electrical forces between charged ions. (They also change the "effective diameter" of the ions by forming a "hydration sheath" around them, but this does not basically affect the validity of the theory.) The solvent can thus be taken account of simply by introducing a dielectric constant in the force law, and only the ions need be explicitly considered. At low concentrations the osmotic pressure plays the same role as the pressure in the gas laws. The effect of the electrical forces on the osmotic pressure might be calculated from statistical mechanics in the same way as one calculates virial coefficients of gases, except that the

corresponding integrals diverge for inverse square forces. The ordinary virial series expansion is not appropriate, and some other method must be devised.

The first attack on this problem was made by Milner in 1912, and was only partially successful. Debye and Hückel (1923) then proposed another method which yielded the correct limiting laws for extremely dilute solutions in a simple and elegant manner, but which could not easily be extended to higher concentrations in a way consistent with the basic principles of statistical mechanics. However, the work of Debye and Hückel inspired a large number of theoretical and experimental investigations, many of which may be of interest in the study of ionized gases where experiments are much more difficult.

While in the theory of solutions of strong electrolytes one usually assumes complete dissociation at low concentrations, "association" being reserved to explain anomalous behavior at higher concentrations, in ionized gases it is usually necessary to take explicit account of the equilibrium between ionized, dissociated, and normal molecular species. The major calculational effort is expended on determining the composition of the gas, and the pressure is usually assumed to be that of an ideal gas, the electrical or "Debye-Hückel" corrections being ignored as an unnecessary refinement. When the temperature and pressure are so high that electrical effects on the pressure can no longer be ignored, quantum-mechanical and relativistic effects must also be considered.

Although approximate "realistic" theories of electrolyte solutions, emphasizing hydration effects, may thus be superficially quite different from approximate "realistic" theories of ionized gases, emphasizing bound state effects, there continues to be a distinct resemblance between fundamental treatments of idealized models. The methods of Bogolyubov and Mayer, and techniques borrowed from quantum field theory, have been applied to classical and quantum systems of charged particles; the result will probably be a unified theory of both electrolyte solutions and ionized gases.

For surveys of the field we recommend the cited book of Falkenhagen (1932) on early theories of electrolytes, the article of Falkenhagen and Kelbg (1959) on recent work, and the report of Duclos (1960) on ionized gases.

Papers on the equation of state of matter at high density (Thomas-Fermi method, degenerate electron gas, etc.) have been omitted as they are covered in another bibliography (Lane 1960).

We are indebted to Hugh DeWitt, Gilda Harris, and Howard Levine for several references and suggestions.

ABBREVIATIONS

CA	Chemical Abstracts
DH	Debye-Hückel
PA	Physics Abstracts
PB	Poisson-Boltzmann
p.f.	Partition function
QM	Quantum-mechanical
TF	Thomas-Fermi
*	(indicates reference not seen by us)

BIBLIOGRAPHY

1. Abe, R.: Equation of state of classical electron gas. *Progr. Theoret. Phys. (Kyoto)* 21, 475-476 (1959).

If Ichikawa's results (1958) are correct, it should be possible to derive them from the cluster expansion method without using collective coordinates. The results (discussed in detail in following ref.) indicate that the DH law is exact to terms in order λ ($= 2\sqrt{\pi} \beta^{3/2} \rho^{1/2} \epsilon^3$) for pure Coulomb interactions.

2. Abe, R.: Giant cluster expansion theory and its application to high temperature plasma. *Progr. Theoret. Phys. (Kyoto)* 22, 213-226 (1959).

"The conventional virial expansion of thermodynamic functions is converted into a new expansion scheme, similar to the former but more powerful. The new method is particularly suitable to dealing with the interaction of long-range character, such as Coulomb potential, since it suffers from no divergence difficulties contrary to the conventional one. As an application of the method, the equilibrium properties of high temperature plasma is studied and the term of next higher orders than the DH limiting law is obtained exactly..."

This term is obtained as a definite integral,

$$S_2 = 2\pi\rho^2 \int_0^\infty [e^{-\beta q(r)} - 1 + \beta q(r) - \beta^2 q^2(r)/2] r^2 dr$$

where $q(r)$ is a screened potential obtained from the real potential by summing certain types of diagrams. Similar results were obtained by Meeron (1958), Friedman (1959), and Yukhnovskii (1958).

Accascina, F.: see Fuoss, R. M.

3. Akhiezer, I. A., and Peletminskii, S. V.: Application of quantum field theory methods for investigation of the thermodynamical properties of

an electron and photon gas. Zhur. Eksptl. i Teoret. Fiz. 38, 1829-1839 (1960). Soviet Phys. JETP 11, 1316-1322 (1960).

"The thermodynamic potential $[\Omega]$ of a gas of electrons, positrons, and photons is determined by the methods of field theory, taking account of the interaction between these particles with an accuracy up to terms proportional to $e^4 \ln e^2$."

4. Alekseev, A. I.: Primenenie metodov kvantovoi teorii polya v statisticheskoi fizike. Uspekhi Fiz. Nauk 73, 41-88 (1961). Soviet Phys. Uspekhi (in press).

Review of applications of quantum field theory methods (esp. those of Schwinger and others) in statistical mechanics; the example of electron-ion systems is briefly discussed.

5. Alpher, R. A.: The Saha equation and the adiabatic exponent in shock wave calculations. J. Fluid Mech. 2, 123-126 (1957).

In a recent paper (Guman, J. Appl. Phys. 27, 663 (1956)) "the reader is not cautioned about including excited states in the Saha equation for the degree of ionization behind shock fronts at appropriate temperatures and densities." Alpher presents a brief discussion of the effects of including these excited states, assuming that only those electrons whose classical orbits do not exceed half the mean separation of particles in the gas are counted as bound to the corresponding atom or ion.

6. Bagchi, S. N.: A new equation for strong electrolytes. I, II. J. Indian Chem. Soc. 27, 199-203, 204-213 (1950).

The number of positive and negative ions per unit volume around a central ion is assumed to be given by the expression $n_{\pm} = N / (\exp \{ \pm \epsilon \psi / kT \} + 1)$ where $N = \sum n_i$. Expressions for the activity coeff. based on this equation are given. In part II the equation is generalized to any binary electrolyte and the calcd. activity coeffs. are compared with experiments.

7. Bagchi, S. N.: On strong electrolyte solutions. Naturwissenschaften 39, 299-300 (1952).

The distribution function derived earlier (Dutta and Bagchi 1950) is used to calculate activity coeffs. The results are compared with those of Gronwall, La Mer, and Sandved (1929).

Bagchi, S. N.: see also Dutta, M.

8. Bardeen, J.: Electron exchange in the theory of metals. Phys. Rev. 50, 1098 (1936). Abstract. "The specific heat of free electrons goes to zero at $T = 0$ as $aT / \log(\epsilon / kT)$."

Baumann, G.: see Kaeppler, H. J.

9. Bazarov, I. P.: Equations with variational derivatives in statistical equilibrium theory. Zhur. Eksptl. i Teoret. Fiz. 32, 1065-1077 (1957). Soviet Phys. JETP 5, 872-882 (1957).

A general method for calculation of correlation functions and free

energy in a system with Coulomb forces is formulated, but no detailed calculations are presented.

10. Bazarov, I. P.: Statistical theory of systems of charged particles with account of short range forces of repulsion. Zhur. Eksptl. i Teoret. Fiz. 32, 1163-1170 (1957). Soviet Phys. JETP 5, 946-952 (1957).
 "The free energy of an electrically neutral system of charged particles (ions) has been found by taking into account the repulsive forces between them. The general expression obtained for the free energy of such systems is applied to its calc. for a concrete form of 'long-range' and 'short-range' forces."
11. Becker, R.: Über die thermische Ionisierung von Gasen und die ihr zugrunde liegenden Elementarprozesse. Z. Physik 18, 325-343 (1923).
 "A fundamental viewpoint of the mechanism of thermal ionization is better obtained from a study of monatomic and monovalent gases than from any other chemical reaction... Section 1 deals with the equilibrium formula according to quantum statistics. Section 2 considers the statistical weights of the various stationary states. Section 3 investigates the emission and absorption mechanism of radiation processes. Section 4 then deals with the non-radiating emission and absorption of electrons..." -- H. H. Hodgson, PA 27, 196 (1924).
12. Beckett, C. W., Green, M. S., and Woolley, H. W.: Thermochemistry and thermodynamics of substances. Ann. Rev. Phys. Chem. 7, 287-310 (1956).
 Developments in the eq. of state at very high pressures and temperatures; quantum statistical mechanics and the TF method; static and dynamic high pressure compression measurements; gases at high temperatures and moderate density. 126 references.
13. Beckett, C. W., and Haar, L.: Thermodynamic properties at high temperatures: Ideal gas thermal functions to 25,000 deg. K for diatomic molecules, oxygen, nitrogen, nitric oxide, and their molecule ions. Proc. Conf. on Thermodynamics and Transport Properties of Fluids, London, 1957, p. 27-33. Institution of Mech. Engineers, London (1958).
 Beckett, C. W.: see also Hilsenrath, J.
14. Benson, G. C.: An examination of Mayer's theory of ionic solutions. The calculation of the relative apparent molal heat content and apparent molal volume of sodium chloride in aqueous solutions at 25° C. Can. J. Chem. 32, 802 (1954).
 "Mayer's theory gives a good representation of the apparent molal volume Φ_V of sodium chloride in aq. soln. at 25° C. up to a conc. of 0.4 molar. Representation of the relative molal heat content Φ_L is also satisfactory but over a smaller range of conc. The shape of the Φ_L curve is also satisfactory but over a smaller range of conc. The shape of the Φ_L curve is strongly influenced by the temp. dependence

of the distance of closest approach of oppositely charged ions in the solution. Methods of evaluating this term are considered. " Some errors in Poirier's formulae (1953) are pointed out.

15. *Benson, S. W., Buss, J. H., and Myers, H.: Thermodynamic properties of ionized gases. Institute of Aeronautical Sciences paper no. 59-95. June 1959. Cited by Duclos (1960).
16. Berlin, T. H., and Montroll, E. W.: On the free energy of a mixture of ions: An extension of Kramers' theory. J. Chem. Phys. 20, 75-84 (1952).

"The primary physical assumptions are: (1) point ions, and (2) small fluctuations. . . . The modification [of Kramers' theory (1926)] consists of a more physically accurate development of assumption (2). The main result of the present theory is that a p.f. for the electrolyte is obtained at all concns., whereas Kramers' theory breaks down beyond a limiting conc. The deviation from the DH limiting law is in the direction of the exptl. observations. "

17. *Bethe, H. A.: Report on the specific heat of air up to 25,000° C. OSRD 369 (1942).
18. Bienkowski, G. K.: The equation of state of an ionized gas, II. MIT-NSL-398; ASTIA Document AD 235 973; WADD-TR-59-486 (pt. II). Sept. 1959.

Equilibrium p.f.'s were investigated; the eqns. which can determine the distribution functions are hopelessly nonlinear except for asymptotic regions and therefore approx. solutions are derived for the nonlinear range and quantum effects in the ion-electron interactions are included. The resulting distributions are used to calc. the eq. of state. The relation thus obtained is found to lie near the DH eq. of state, but closer to the perfect gas relation. This is a result of the excessive correlation predicted by DH theory because of its neglect of quantum effects. The effect, however, is small for reasonable pressures, thus justifying the use of the DH theory in this region. Higher order effects resulting from the volume of the particles and attractive forces between the charged and neutral particles are evaluated and found to be at least an order of magnitude smaller than the Coulombic effects in this region. The pair distribution function was calcd. by the method of Brittin (1957) following a suggestion of Eddington (1925); it takes into account the volume of the ions and polarization of neutral atoms by ions.

19. Bjerrum, N.: Untersuchungen über Ionenassoziation. I. Der Einfluss der Ionenassoziation auf die Aktivität der Ionen bei Mittleren Assoziationsgraden. Kgl. Danske Videnskab. Selskab Mat.-Fys. Medd. 7, no. 9 (1926).

Extends DH theory to higher concns. by taking account of ionic association. Reviewed by Falkenhagen (1932) §51.

20. Bjerrum, N.: Die Verdünnungswärme einer Ionenlösung in der Theorie von Debye und Hückel. Zugleich ein Beitrag zur Theorie der Wärmeeffekte in einem Dielektrikum. *Z. physik. Chem. (Leipzig)* 119, 145-160 (1926).

"B. calcs. the heat of diln. from the elec. work of sepn. of the ions of an electrolyte. This is dependent on the temp. coeff. of dielec. const. The heat of diln. is a special case of the general problem of heat effects caused by movement of charges in a dielectric. The equation is derived for dil. solns. and does not agree with exptl. data for heat of diln. of conc. solns. The problem is also discussed from an atomistic standpoint." -- B. H. Carroll, *CA* 20, 1940 (1926).

Discusses a charging process suggested by Guntelberg; cf. Fowler and Guggenheim (1939), Guggenheim (1960).

21. Bjerrum, N.: The electric forces between ions and their activity (in Norwegian). *Svensk Kem. Tidskr.* 38, 2-18 (1926).
Bockris, J. O'M.: see Körtum, G.
22. Bogolyubov, N. N.: Expansions into a series of powers of a small parameter in the theory of statistical equilibrium. *J. Phys. (U.S.S.R.)* 10, 257-264 (1946).

Equations are derived connecting the distribution functions of different orders in the case of statistical equilibrium. These equations are solved with the help of the expansions into a series of powers of the density, and the formal expressions of the theory of Ursell-Mayer are obtained without application of their combinatorics. The case of Coulomb interaction is also studied, for which a special expansion method is developed. An approx. integral eqn. for the binary distribution function is derived, which apparently can be used for the description of the condensed state.

23. Bogolyubov, N. N.: Problemy dinamicheskoi teorii v statisticheskoi Fizike. Gos. Izd. Tekh.-teor. Lit. Moscow (1946). English translation (E. K. Gora): Problems of a Dynamical Theory in Statistical Physics. AFCRL-TR-60-279; AFCRC-TR-59-235; ASTIA Document AD-213 317.

More elaborate development of the method outlined in preceding reference. When applied to a system of charged particles the method yields the DH results in first approximation; suggestions are made about the possibility of obtaining higher approximations.

24. Bond, J. W., Jr.: The structure of a shock front in argon. Los Alamos Sci. Lab. Rept. LA-1693 (1954).

"A method of computing the equilibrium conditions, which was first applied by Bethe to air, has been used for the argon equilibrium reaction $A = A^+ + e$, where only singly-ionized argon atoms have been considered. The corresponding p.f.'s for density ratios from 2 to 20 and temperatures from 7500° to 26,000° are tabulated." See Bethe (1942).

25. Bonino, G. B.: Ricerche sulla teoria delle soluzioni concentrate di elettroliti forti. I. Considerazioni teoriche. Mem. reale accad. Italia, Classe sci. Fis., mat. e nat. 4, 415-444 (1933).
 "A comprehensive review and critique of developments of the DH theory. 'Secondary activity' coeffs. are calcd., showing deviations from the DH theory, from physical constants of ions and solvent." -- G. W. King, CA 28, 4967 (1934). About 50 references. See also Brüll (1934).
26. Bonino, G. B., and Centola, G.: Ricerche sulla teoria delle soluzioni concentrate di elettroliti forti. II. Applicazione al calcolo dei coefficienti di attività. Mem. reale accad. Italia, Classe sci. Fis., mat. e nat. 4, 445-464 (1933).
27. Bonino, G. B., and Centola, G.: Ricerche sulla teoria delle soluzioni concentrate di elettroliti forti. Possibilita di estensione al calcolo dei coefficienti osmotici. Mem. reale accad. nazl. Lincei, Classe sci. Fis., mat. e nat. 18, 145-149 (1933).
 "Following the previous calcn. of the coeffs. of activity of the ions of strong electrolytes in conc. soln., these calcs. are developed in the present paper so as to be able to arrive at ... the osmotic coefficients..." - J. J. Stewart, PA 36, 1275 (1933).
28. Bosnjakovic, F., Springe, W., Knoche, K. F., and Burgholte, P.: Mollier enthalpy-entropy charts for high temperature plasmas. Thermodynamic and Transport Properties of Gases, Liquids, and Solids, p. 465 McGraw-Hill Book Company, New York (1959). Also: RAND Translation T-96 (1958).
 "... Mollier enthalpy-entropy diagrams for hydrogen and argon plasmas up to 100,000° K and for pressures from 0.01 to 100 atm."
29. Bowers, D. L., and Salpeter, E. E.: Correction to the Debye-Hückel theory. Phys. Rev. 119, 1180-1186 (1960).
 Corrections are derived for the potential of mean force and the interaction energy by solving an integral equation previously derived by Salpeter (Annals of Physics 5, 183 (1958)). The numerical values of the interaction energy for a classical electron gas with uniform positively-charged background are comparable to those calculated from Abe's S_2 integral (cf. Abe 1959, Trulio and Brush 1961).
30. *Brinkley, S. R., Kirkwood, J. G., and Richardson, J. M.: Tables of the properties of air along the Hugoniot curve and the adiabatics terminating in the Hugoniot curve. OSRD 3550 (1944).
31. *Brittin, W. E.: Equilibrium and Transport in a fully ionized gas. Doctoral Dissertation, University of Alaska (1957).

32. Brittin, W. E.: Investigation of the equilibrium properties of fully ionized gases. Second quarterly report, PEC-LIV-1 (1959); Seventh quarterly report, PEC-LIV-5, TID-6265 (1960); Final report, TID-11029 (1960).

"The method to be used will be essentially that developed by Montroll and Ward (1958)... The present preliminary report outlines the method of Montroll and Ward from the standpoint of field theory and includes a new modification developed by A. Sakakura..." (PEC-LIV-1)

Further results of numerical calculations for a binary plasma equation of state were presented in PEC-LIV-5. See Nuclear Sci. Abstr. 15, 1773 (1961).

Brittin, W. E.: see also Covert, E. E.

33. Brüll, L.: Ricerche su una recente teoria per le soluzioni concentrate di elettroliti forti. Gazz. chim. ital. 64, 270-278 (1934).

"The fundamental differences between the theory of Bonino et al. (1933) and that of DH are examined critically and on a math. basis. A formula of interpolation is derived which according to representative calc. with various solns. of chlorides gives a good degree of approximation (within 1%) and at the same time renders calcs. of the coeffs. of activity simpler." -- C. C. Davis, CA 28, 4966 (1934).

Brush, S. G.: see Trulio, J. G.

34. Burhorn, F., and Wienecke, R.: Berechnung der inneren Zustandssummen einiger zweiatomiger Molekule bei höheren Temperaturen. Z. physik. Chem. (Leipzig) 212, 105-117 (1959).
35. Burhorn, F., and Wienecke, R.: Plasmazusammensetzung, Plasmadichte, Enthalpie und spezifische Wärme von Sauerstoff bei 1, 3, 10, 30 atm in Temperaturbereich zwischen 1000 und 30,000° K. Z. physik. Chem. (Leipzig) 213, 37-43 (1960).
36. Burhorn, F., and Wienecke, R.: Plasmazusammensetzung, Plasmadichte, Enthalpie und spezifische Wärme von Stickstoff, Stickstoffmonoxyd und Luft bei 1, 3, 10 und 30 atm in Temperaturbereich zwischen 1000 und 30,000° K. Z. physik. Chem. (Leipzig) 215, 269-284 (1960).
37. Burhorn, F., and Wienecke, R.: Plasmazusammensetzung, Plasmadichte, Enthalpie und spezifische Wärme von Wasserstoff und Wasser bei 1, 3, 10 und 30 atm in Temperaturbereich zwischen 1000 und 30,000° K. Z. physik. Chem. (Leipzig) 215, 285-292 (1960).

Centola, G.: see Bonino, G. B.

38. Carr, W. J., Jr.: Energy, specific heat, and magnetic properties of the low density electron gas. Phys. Rev. 122, 1437-1446 (1961).

"A perturbation expansion in powers of $r_s^{-1/2}$ has been used to investigate the ground-state energy of a dilute electron gas, the result

being, in rydberg units per particle, $E = -1.792/r_s + 2.66/r_s^{3/2} + b/r_s^2 + 0(r_s^{-5/2}) +$ terms falling off exponentially with $r_s^{1/2}$. The dimensionless parameter r_s is the radius of the unit sphere in Bohr radii. The term in r_s^{-1} is the energy of a body-centered cubic lattice of electrons as calculated by Fuchs; the $r_s^{-3/2}$ term is the zero-point vibrational energy of the lattice, as obtained from a calculation of the normal modes, the result differing only by a small amount from the values estimated by Wigner; and br_s^{-2} is the first-order effect of anharmonicities in the vibration. The constant b has been estimated, its magnitude being smaller than unity.

"The vibrational part of the specific heat has been calcd., and a first-order approx. has been obtained for the exponential terms in the energy. Part of this energy comes from exchange, which leads to the result that, except for very low densities ($r_s > 270$), the electron spins are antiferromagnetically aligned. An order of magnitude for the Néel temperature has been calcd."

39. Chandrasekhar, S.: The Ionization-Formula and the new statistics. *Phil. Mag.* (series 7) 9, 292-299 (1930).

Modification of Saha's formula to take account of Fermi-Dirac statistics for the electrons.

40. Chandrasekhar, S.: The dissociation formula according to the relativistic statistics. *Monthly Notices Roy. Astron. Soc.* 91, 446-455 (1931).

Formulae for concentrations of ions and electrons including quantum and relativistic effects. Extension of results of Milne (1930).

41. Claas, W. J.: The composition of the solar atmosphere. *Recherches Astron. Obs. Utrecht* 12, Part 1 (1951).

Partition functions for various elements, 4900° to 7300°.

42. Covert, E. E., and Kerney, K.: A review of the literature of plasma physics. WADC-TR-59-486; MIT-NSL-TR-373 (1959). ASTIA Document AD 227 556.

The applicability of the DH theory for describing equilibrium properties of a plasma is discussed. The results of Kaeppler and Baumann (1956) are quoted for the thermodynamic functions of a system of several kinds of ions.

43. Covert, E. E., Bienkowski, G. K., Kerney, K. P., King, M. F., and Pedlosky, J.: Final report on research on a comprehensive theory of plasma states and phenomena. WADD-TR-59-486 (pt. IV); MIT-NSL-TR-441 (1960).

"The material is covered more completely in report WADD-TR-59-486, parts I, II, III (MIT NSL Tech. Repts. 373, 398, 399, resp.) The thermodynamic state equation of a plasma, the influence of the magnetic field on the transport properties, as well as the thermodynamic state; and elementary fluid flow problems are summarized." The material on eq. of state of ionized gases is taken from WADD-TR-486 (pt. II); see Bienkowski (1959).

44. Cowan, R. D., and Kirkwood, J. G.: Debye-Hückel, Thomas-Fermi theory of plasmas and liquid metals: numerical solution. AECU-3616 (1957).

"A DH type theory is described for an assembly of completely ionized atoms, the nuclei being treated classically and the electrons by the TF method. The thermodynamic functions are derived by considering the Debye charging process, and the virial theorem is shown to hold. Numerical results are given for hydrogen and iron near normal solid densities, and are probably accurate only at high temperatures ($kT > 5$ ev for hydrogen and $kT > 100$ ev for iron)." See Plock (1957).

45. Cowan, R. D., and Kirkwood, J. G.: Quantum statistical theory of plasmas and liquid metals. J. Chem. Phys. 29, 264-271 (1958).

DH type theory for an assembly of completely ionized atoms, the nuclei being treated classically and the electrons by the TF method. Cf. Kidder and DeWitt (1961).

46. Cowan, R. D., and Kirkwood, J. G.: Quantum statistical theory of electron correlation. Phys. Rev. 111, 1460-1466 (1958).

"The average electrostatic potential distribution about a given electron is calcd. for a system of point-charge electrons imbedded in a neutralizing continuum of positive charge. The calculation is classical, involving a Poisson equation of the DH type, except that the electron density is treated by means of FD statistics as in the TF model of the atom. The calcd. energy due to electrostatic interactions agrees with the QM exchange plus correlation energy over the observed range of metal valence-electron densities, $2 \leq r_s \leq 6$, but is too small at larger and smaller densities..."

47. Creighton, H. J.: Principles and Applications of Electrochemistry. Volume I. Principles. 4th edition. John Wiley & Sons, New York (1943).

Chapter XV "Theories of Strong Electrolytes" reviews the Milner, DH, and Bjerrum theories.

48. Davies, D. R.: Shock waves in air at very high pressures. Proc. Phys. Soc. (London) 61, 105-117 (1948).

"...it is necessary to know the internal energy (E) and volume (v) of one gramme of air over certain regions of the two-dimensional range $1 < p < 1000$ atm and $273 < T < 16,000^\circ$ K. Calculations are carried out to assess the numbers of the various types of molecules, atoms, and ions present at any p and T. The only E values needed at high p are those for which T is also high, and the simple gas laws may therefore be assumed for the volume determinations. The resultant energy is obtained by summing the internal energies of different groups of atoms and molecules present. Statistical mechanics furnishes the equations whose solution fixes the composition..."

49. Debye, P.: De moderne ontwikkeling der elektrolyttheorie. Handelingen van het XIX^{DE} Nederlandsch Natuur- en Geneeskundig Congres, 40-50. Maastricht, 1923.

Historical review of theory of electrolytes previous to DH theory.

50. Debye, P.: Over Ionen en Hun Activiteit. Chem. Weekblad 20, 562-568 (1923); The Collected Papers of Peter J. W. Debye (Interscience Publishers, New York, 1954) 311-325.
51. Debye, P., and Hückel, E.: Zur Theorie der Elektrolyte. I. Gefrierpunktserniedrigung und verwandte Erscheinungen. Physik. Z. 24, 185-206 (1923); Collected Papers, 217-263.

"The present considerations were stimulated by a lecture by E. Bauer on Ghosh's works.... W. Sutherland, in 1907, intended to build the theory of electrolytes on the assumption of complete dissociation. N. Bjerrum (Proc. 7th Int. Congress of App. Chem., London, 1909) is, however, the first to have arrived at a distinct formulation of the hypothesis. He clearly stated and proved that, for strong electrolytes, no equilibrium at all is noticeable between dissociated and undissociated molecules.... Milner (1912, 1913) computed the osmotic coefficient along such lines... it would be unjust to discard Milner's computation in favor of the more recent computations by Ghosh (1918) on the same subject..." The work of Hertz, Ann. Physik 37, 1 (1912) on conductivity is also mentioned.

This paper contains the famous DH theory based on the solution of the linearized PB equation. Milner's comments on the advantage of the DH theory over his own are recorded by Nonhebel and Hartley (1926).

52. Debye, P., and Hückel, E.: Zur Theorie der Elektrolyte. II. Das Grenzgesetz für die elektrische Leitfähigkeit. Physik. Z. 24, 305-325 (1923); Collected Papers, 264-310.

"...an attempt is made to compute, assuming complete dissociation, in which manner the mutual electric forces of the ions affect the conductivity..."

53. Debye, P.: Osmotische Zustandsgleichung und Aktivität verdünnter starker Elektrolyte. Physik. Z. 25, 97-107 (1924); Collected Papers, 326-346.

"The theory of strong electrolytes published some time ago was presented in a manner which permits considerable simplification, as I have since found out." Lewis's laws on the activity of strong electrolytes are explained by the theory.

54. Debye, P., and McAulay, J.: Das elektrische Feld der Ionen und die Neutralsalzwirkung. Physik. Z. 26, 22-29 (1925); Collected Papers, 355-365.
55. Debye, P., and Pauling, L.: The inter-ionic attraction theory of ionized solutes. IV. The influence of variation of dielectric constant on the limiting law for small concentrations. J. Am. Chem. Soc. 47, 2129-2134 (1925); Collected Papers, 615-620.

Conclusion: "...neither the variation of the dielectric constant in the immediate neighborhood of the ions nor the deviation of the dielectric constant of the solution in mass from that of the pure solvent has any effect on the limiting law for very dilute solutions of strong electrolytes. It is further proved that for such solns. the value of the ordinary dielectric constant for the pure solvent in mass is to be substituted. The experiments of Bronsted and La Mer [ibid. 46, 555 (1924)] at very low concs. have completely confirmed the theoretical limiting law."

56. Deubner, A.: Thermodynamik und Elektrophysik flüssiger Elektrolyt-lösungen. 2. Physik regelmäss. Ber. 8, 97-112 (1940).
Sequel to Falkenhagen's review article (1936).
57. DeWitt, H. E.: Wave mechanical modifications of the equation of state of an electron gas. Bull. Am. Phys. Soc. 5, 7 (1960).
58. DeWitt, H. E.: Thermodynamic functions of a partially degenerate, fully ionized gas. J. Nuclear Energy (Part C) 2, 27-45 (1961).

"The formalism of Glassgold, Heckrotte, and Watson [Phys. Rev. 115, 1374 (1959)] for the expansion of the QM grand p.f. has been applied to a gas of point charges. The expansion is shown to be closely related to Rayleigh-Schroedinger perturbation theory, and to give the results of Montroll and Ward (1958) in a simpler form. The theory has been extended to a multicomponent gas of fermions and bosons, and the ring diagrams have been summed to give an approximate expression for the equation of state valid for the entire temperature range. The near-classical (high temperature and low density so that the gas is only slightly degenerate) limit is discussed in detail, and useful formulae for numerical computation of pressure and internal energy are derived from the general ring approximation to the equation of state. By expanding the chemical potential in powers of the coupling constant e^2 , it is possible to eliminate the parametric dependence of pressure and density on the chemical potential and obtain the pressure as a function of density. The classical-limit DH results are obtained when \hbar approaches 0. A general form of the screening length is obtained with the effective screening charge as $z_i e \Theta_i$, where Θ_i is a measure of the degeneracy of the particle species i . The contribution to the pressure from the simplest exchange interaction valid for all temperature is evaluated exactly. The temp. and density range for which the near-classical-limit formulae are valid is discussed."

See also: Bloch, de Dominicis, and Horowitz, AEC-tr-3865, translated from Nuclear Phys. 7, 451, 8, 91, 7, 459 (1958), 10, 181, 509 (1959); Levine (1960).

59. DeWitt, H. E.: Quantum mechanical modification of the Meeron nodal expansion. Bull. Am. Phys. Soc. 6, 14 (1961).
DeWitt, H. E.: see Kidder, R. E.
60. Duclos, D. P.: The equation of state of an ionized gas. AEDC-TN-60-192 (1960).

"The equation of state of an ionized gas has been investigated for electron densities below about 10^{22} per cm^3 and temperatures below about $1,000,000^\circ \text{K}$. The gas is assumed to be monatomic, electrically neutral, and in thermodynamic equilibrium, but the composition of the gas is arbitrary, that is, multiple ionization of any degree is allowed. The perfect gas approx. is found to be valid for electron densities at least as high as 10^{16} per cm^3 and, in some cases, even higher. It is shown that approximations to the perfect gas expressions can be made which will greatly simplify calculations. It is also shown that black-body radiation may be important at low densities. The classical corrections to the perfect gas expressions due to electrostatic forces and the finite size of particles which are obtained from the theories of Debye and Hückel, Mayer, and others, are investigated, and their limits of validity are determined. In some cases, improved expressions are derived and suitable approximations are suggested. It is noted that a fundamental weakness of the results based on these theories is that a basic parameter, the distance of closest approach of charged particles, is not known accurately. Several approximate expressions for this distance are given. Quantum corrections for electron degeneracy and electron interactions are also given. Theories which are applicable at higher densities and temperatures than those of interest in this investigation are also discussed briefly. Finally, the equation of state of a dense, slightly ionized gas is derived." 78 refs.

61. Dumezil-Curien, P.: Entropie d'un mélange de gaz en équilibre d'excitation et d'ionisation. *Compt. rend.* 232, 1471-1472 (1951).

"Generalizes the expression obtained by Schatzman (1948) who neglected the excited states of the atoms and ions." -- P. M. Davidson, *PA* 54, 713 (1951).

62. Dutta, M.: On Bagchi's calculation of activity coefficients by the method of Gronwall and his collaborators. *Naturwissenschaften* 39, 569-570 (1952).

"Recently Bagchi (1952) has calcd. activity coeffs. by means of the Dutta-Bagchi (1950) distribution formula, which is corrected for the volume actually occupied by the water molecules, and then applied to the method of Gronwall, LaMer, and Sandved (1928). This application is shown to be unjustified, and it is pointed out that good agreement is obtained between observed and calcd. activity coeffs. by use of Dutta's formula (*Naturwiss.* 39, 108) without introduction of the above correction." -- H. H. Hodgson, *PA* 56, 369 (1953).

63. Dutta, M.: A quasi-lattice theory of real gases and of strong electrolytes in solutions. *Proc. Natl. Inst. Sci. India* 19, 183-194 (1953).

"The theory is similar to the theory of solids developed by Frenkel and others, and to that of liquids by Lennard-Jones and Devonshire..."

64. Dutta, M., and Bagchi, S. N.: On the distribution of ions in solutions of strong electrolytes. *Indian J. Phys.* 24, 61-66 (1950).

"In a recent paper it has been shown that a better and closer agreement between the theoretical and experimental values of activity

coeffs. are obtained if instead of Boltzmann's distribution functions a new distribution function, similar in form to that of Fermi-Dirac, be used in the DH theory of strong electrolytes. No deduction has been given yet for the function used by Bagchi. In this paper, the distribution function has been deduced from simple physical properties of ions by a method developed by Dutta [Proc. Natl. Inst. Sci. India 13, 247 (1947); 14, 163 (1948)]."

See also Bagchi (1950, 1952) and Dutta (1952).

65. Ecker, G., and Weizel, W.: Zustandssumme und effective Ionisierungsspannung eines Atoms im Innern des Plasmas. Ann. Physik. 17, 126-140 (1956); AEC-tr-2841.

Lowering of ionization potentials of atoms in plasmas when degree of ionization is appreciable. See Duclos (1960), p. 44-50, or PA 59, 481 (1956). See also ref. 341.

66. Ecker, G., and Weizel, W.: Zustandssumme und effective Ionisierungsspannung im Innern des Plasmas. Z. Naturforsch. 12a, 859-860 (1957).

"Criticizes an approximate evaluation of the electrostatic interaction energy by Theimer (1957) because it unjustifiably assumes stochastic independence of the charged particles." -- B. Meltzer, PA 62, 678 (1959).

67. Ecker, G., and Weizel, W.: Über die Wechselwirkungsenergie der Ladungsträger in einem Plasma. Z. Naturforsch. 13a, 1093-1094 (1958).

Reply to Theimer (1958). See PA 62, 678 (1959).

68. Eddington, A. S.: On the relation between the masses and luminosities of the stars. Monthly Notices Roy. Astron. Soc. 84, 308-332 (1924).

Effect of extreme compression on matter, possible deviations from gas laws.

69. Eddington, A. S.: Electrostatic forces in a star and the deviation from the laws of a perfect gas. Monthly Notices Roy. Astron. Soc. 86, 2-8 (1925).

Points out that one must consider the quantum effects which prevent the electron from having infinite negative energy. Cf. Rosseland (1924), Fowler and Guggenheim (1925).

70. Eddington, A. S.: The Internal Constitution of the Stars. Cambridge University Press (1926); Dover Publications, New York (1959).

Possible application of DH theory, §182: ff. Eddington concludes that at high densities and temperatures there is nearly complete ionization, and the effect of electrical forces between ions is to increase the compressibility rather than decrease it. The bare nuclei and electrons will behave like a perfect gas up to very high densities.

71. Edwards, S. F.: A variational calculation of the equilibrium properties of a classical plasma. Phil. Mag. (series 8) 3, 119-124 (1958).

"A variational calculation is given for the free energy of a fully ionized classical plasma. The method avoids redundant variables and allows for cross terms between collective and individual modes of oscillation, though these turn out to be small. A relation is given for the shielding distance in terms of the DH radius and the inter-particle distance, it being of the order of the former."

72. Edwards, S. F.: The statistical thermodynamics of a gas with long and short range forces. *Phil. Mag. (series 8)* 4, 1171-1182 (1959).

"If a gas has long-range Coulomb interactions and short-range interactions, e. g. hard core repulsions, three lengths enter the problem; the radius of the repulsive core, d , the mean interparticle distance, r_0 , and λ_D , the DH radius, $(8\pi Ne^2/VkT)^{-1/2}$. This paper presents a method of obtaining the equation of state when, in the first instance $\lambda_D \gg r_0 \gg d$, which enables one to obtain higher-order terms in a simple way, and these are calculated. In order to relax the condition $\lambda_D \gg r_0$, a variational method is employed which shows that the usual DH theory makes the grand thermodynamic potential an extremum, the exact result lying between the perfect gas and the DG gas. The results enable one to estimate the contributions to the virial expansion of collective oscillations and of shielded particle encounters, whilst avoiding difficulties such as are associated with redundant coordinates. The extension of the results to the QM case are briefly commented upon."

73. Eggert, J.: Über den Dissoziationszustand der Fixsterngase. *Physik. Z.* 20, 570-574 (1919).

Ionization equilibrium in a star is discussed, using Nernst's equilibrium formula (Die theoretischen und experimentellen Grundlagen des neuen Wärmesatzes (1918) Kapitel XI).

74. Eigen, M., and Wicke, E.: Zur Theorie der starken Elektrolyte. *Naturwissenschaften* 38, 453-454 (1951).

"The theory is developed on the assumption that ions and their hydrate shells when assigned characteristic volumes in the electrolyte solutions, afford the necessary distribution functions for the calc. of activity coeffs. Comparative curves are shown for results with univalent electrolytes and those calcd. on the DH theory." -- H. H. Hodgson, *PA* 55, 480 (1952).

75. Eigen, M., and Wicke, E.: The Thermodynamics of Electrolytes at higher concentrations. *J. Phys. Chem.* 58, 702-714 (1954).

Summary of their previous papers. "In addition to the electrostatic interaction of the ions two properties of the electrolyte prove to be esp. characteristic of the thermodynamic behavior: 1st, the space requirement of hydrated ions in the ionic atmosphere; 2nd, an incomplete dissociation appearing for a large number of electrolytes at higher concs. . . . By introduction of new distribution formulas for the ionic atmosphere, in the theory of Debye and Hückel, which follow from statistical and thermodynamic considerations analogous to adsorption statistics or to Eucken's treatment of hydration shells, the properties of some completely [and incompletely] dissociated electrolytes . . . are calculated. . . ." See Scatchard's discussion remark, *ibid.* 713, and Eigen's reply.

Eigen, M.: see Wicke, E.

76. Elwert, G.: Verallgemeinerte Ionisationsformel eines Plasma. Z. Naturforsch. 7a, 703-708 (1952).

"A theoretical paper concerned with the establishment of ionization balance in a gas discharge plasma. The phenomena allowed for include photoionization, radiative recombination, ionization by electrons, and three-body recombination processes. These effects are studied separately and together, with some discussion also of Saha's equation."--J. D. Craggs, PA 56, 449 (1953).

77. *Enderby, J. A.: The Theory of the Ionic Double-Layer of ions and colloidal particles in electrolyte solutions. Thesis, Kings College, London (1952).

"... applied the Born-Green equation to the theory of strong electrolytes..." -- Falkenhagen and Kelbg (1959).

Epstein, L. F.: see Scatchard, G.

78. Falicov, L. M., and Heine, V.: The many-body theory of electrons in metal, or Has a metal really got a Fermi surface? Advances in Phys. 10, 57-105 (1961).

"... the purpose of this paper is to discuss the electron theory of metals taking the Coulomb force into account from the beginning. We shall not discuss many-electron effects such as plasma oscillations, but limit ourselves to transport phenomena [which are considered to include] electronic specific heat." The calc. of the ground state energy by Hubbard (1958) and Nozières and Pines (1958) and quasi-particle methods are discussed.

79. Falkenhagen, H.: The principal ideas in the interionic attraction theory of strong electrolytes. Revs. Modern Phys. 3, 412-426 (1931).

Includes some remarks on Kramers' results; "It seems to be impossible to calculate the state integral above the ... critical conc. as long as one does not introduce the finite diameter of the ions." Suggests an analogy with Heisenberg's theory of ferromagnetism.

80. Falkenhagen, H.: Elektrolyte. S. Hirzel, Leipzig (1932), 2nd edition 1953. English translation by R. P. Bell, Electrolytes. Oxford University Press (1934).

Ch. VI: Early theories of the anomalies of strong electrolytes (P. Hertz, S. R. Milner, C. Ghosh, Malmström). Ch. VII: Principles of the Debye-Milner theory of strong electrolytes. Ch. VIII: The Thermodynamics of Strong Electrolytes, according to DH theory. Ch. XI: More concentrated solutions (extensions by DH, Bjerrum, Müller, Gronwall, LaMer and Sandved, Nernst). Ch. XII: Statistical foundations of Debye's theory.

81. Falkenhagen, H.: Thermodynamik und Elektrophysik flüssiger elektrolytischer Lösungen. I. Physik. regelmäss. Ber. 4, 145-172 (1936).

"... The earlier work is reviewed in the light of present physical theory. The investigations which have been carried out since 1934 are included in the review." -- F. J. Brislée, PA 39, 1322 (1936). For part II see Deubner (1940).

82. Falkenhagen, H.: Ordnungszustand in flüssigen elektrolytischen Lösungen. Physik. Z. 43, 170-190 (1942).

Review article. "Grundlagen der interionischen Theorie starker Elektrolyte." "Ergebnisse der interionischen Theorie und Vergleich mit dem experimentellen Befund." "Arrheniussche Theorie und interionische Theorie." "Konzentrierte Lösungen." 102 refs.

83. Falkenhagen, H., and Kelbg, G.: Klassische Statistik unter Berücksichtigung des Raumbedarfs der Teilchen. Ann. Physik. (series 6) 11, 60-64 (1952).

"M. Eigen und E. Wicke [1951, 1952, see also Dutta 1947, 1948, 1951, 1952] haben unter Berücksichtigung des Raumbedarfs der Teilchen eine neue Verteilungsfunktion abgeleitet, die bei den Aktivitätskoeffizienten starker Elektrolyte bereits mit Erfolg angewandt wurde. Diese Formel gilt jedoch nur für zwei verschiedene Teilchensorten mit gleichen Besetzungszahlen. Im folgenden wird diese Verteilungsfunktion auf beliebig viele Teilchensorten unterschiedlicher Grösse und somit verschiedener Besetzungszahlen erweitert. Die Ableitung wird mit Hilfe der Statistik ausgeführt."

84. Falkenhagen, H., and Kelbg, G.: The Statistical Interpretation of the theory of Strong Electrolytes. Discussions Faraday Soc. No. 24, 20-24 (1957).

Review of recent attempts to derive the DH theory by strict statistical methods and to state the assumptions and approximations contained in it. The methods of Kirkwood, Mayer, Bogolyubov and others seem to require too much calculation, hence they consider deriving the relation between the potentials of average force and the average electric potentials from the fundamental statistical equations in a simpler way. The work of Glauber and Yukhnovskii (1952, 1953) is summarized, and attempts to introduce the ionic radius are mentioned.

85. Falkenhagen, H.: Die Elektrolytarbeiten von Max Planck und ihre weitere Entwicklung. Max-Planck-Festschrift 1958, p. 11-34. Veb Deutscher Verlag der Wissenschaften, Berlin.

Review of Planck's work and some later developments.

86. Falkenhagen, H., and Kelbg, G.: The Present State of the Theory of Electrolyte Solutions. Chapter I in Modern Aspects of Electrochemistry, No. 2 (ed. by J. O'M. Bockris), Academic Press, New York (1959).

Review of recent work, with more detailed discussion of theories mentioned in ref. 84. The radial distribution function is calculated for some modified Coulomb potentials, and osmotic coefficients are calculated and compared with experiments. Methods based on the

Bogolyubov-Born-Green integral equation, and on Mayer's cluster expansion, are discussed. Theories based on solvation and on distribution functions other than Boltzmann's are considered.

Feduchak, J.: see Rossi, R. E.

87. Finkelstein, B. N.: Zustandsgleichung von Lösungen starker Elektrolyte und Virialsatz. *Acta physicochemica* 3, 753-755 (1935).

"Expressions for the 'electric' free energy, the energy of solution, and the virial law for solutions of strong electrolytes are derived by application of the Gibbs-Helmholtz free-energy principle."--PA39, 287 (1936).

88. Finkelstein, B. N.: The Virial Theorem and the Theory of Strong Electrolytes. *Proc. Cambridge Phil. Soc.* 31, 281-284 (1935).

Discussion of the information about the thermodynamic properties of an electrolyte which can be obtained from purely dimensional considerations. See van Rysselberghe (1933) whose calcs. were shown to be invalid by Halpern (1934); see also Fuoss (1934).

Finkelstein, B.: see also Frenkel, J.

89. Fisher, I. Z.: O Flukuatsiakh zariada v rastvorakh elektrolitov. *Zhur. Fiz. Khim.* 26, 1212-1214 (1952).

"The semi-thermodynamic theory of charge fluctuations in electrolyte solns., as developed by Leontovich (1946) has been improperly applied by Natanson (1951) in a conc. range where it is not valid. Indeed, the conc. (no. of ions per unit vol.) n must be very much smaller than $(\epsilon kT)^3/8\pi e^6$ where ϵ is the dielec. const. of the solvent and e the electronic charge."--M. Boudart, CA 47, 5768 (1953).

90. Förster, F.: Die Entwicklung der Vorstellungen über die Natur der Elektrolyte. *Z. angew. Chem.* 41, 1013-1021 (1928).

Historical review.

91. Fowler, R. H.: Dissociation-equilibria by the method of partitions. *Phil. Mag. (series 6)* 45, 1-33 (1923).

Includes a new derivation of Saha's formula.

92. Fowler, R. H., and Guggenheim, E. A.: Applications of statistical mechanics to determine the properties of matter in stellar interiors. *Monthly Notices Roy. Astron. Soc.* 85, 939-960, 961-970 (1925).

"The contributions which statistical mechanics can make to Eddington's well-known theories [*Z. Physik.* 7, 351 (1921)] of the equilibrium conditions in the interior of a gaseous star are concerned with the properties of the material of which the star is composed." *Stat. mech. can calculate (1) degree of ionization; (2) equation of state; (3) distribution of ions among various states (needed to calc. mean mass abs. coeff.).*

93. Fowler, R. H.: General forms of statistical mechanics with special reference to the requirements of the new quantum mechanics. *Proc. Roy. Soc. (London)* A113, 432-449 (1926).

General formulae for dissociative equilibrium taking account of Bose-Einstein and Fermi-Dirac statistics, derived by method of steepest descents.

94. Fowler, R. H.: Strong electrolytes in relation to statistical theory, in particular the phase integral of Gibbs. *Trans. Faraday Soc.* 23, 434-443 (1927).
- Discussion of statistical basis of DH theory and addition of fluctuation terms to the PB equation. (This is discussed more completely in the following reference.)
95. Fowler, R. H.: Statistical Mechanics: The Theory of the Properties of Matter in Equilibrium. Cambridge University Press (1929). 2nd edition, 1936.
- See §8.7 to 8.82, §13.6 to 13.8, §15.1 to 16.5. Statistical mechanics applied to inverse square forces; fluctuations; charging process; foundations of DH theory and its applications; review of proposed extensions to higher concs.; Gronwall-LaMer-Sandved, Bjerrum, Fuoss; "principle of specific interaction" (Brønsted and Guggenheim); applications to equilibrium of an ionized atmosphere, and stellar interiors. Cf. Onsager (1933).
96. Fowler, R. H., and Guggenheim, E. A.: Statistical Thermodynamics. A version of Statistical Mechanics for students of Physics and Chemistry. Cambridge University Press (1939).
- Ch. IX: "Solutions of Electrolytes." Discusses "whether this complete dissociation of salts is to be expected theoretically." Hydration of ions. Dimensional considerations. Milner's formula. DH theory. Self-consistency of the average potential. Mean thickness of the ionic atmosphere. Dependence on dielectric constant. Ionic diameter. Calc. of osmotic and activity coeffs. Heat of dilution. More accurate solutions of the PB eqn.; its lack of self-consistency. Bjerrum's treatment of ion association. Theory of Fuoss (1934). Specific interaction of ions.
97. Frank, H. S.: Local dielectric constant and solute activity. A hydration-association model for strong electrolytes. *J. Am. Chem. Soc.* 63, 1789-1798 (1941).
- "A new derivation is given for the Debye-Pauling (1925) expression for the effect of local dielectric constant on the electrostatic free energy of a central ion due to its ion cloud. It is shown that if the local dielectric constant is less than 25, and if the ions can approach each other at distances equal to their crystal radius sums, the complete Debye-Pauling expression predicts large negative deviations from the DH limiting law for activity coeffs. even in very dilute solution... in disagreement with experiment... Agreement between experimental activity coeffs. and the predictions of the Debye-Pauling theory can be obtained by assuming that the ions in aqueous soln. are hydrated and that they take part in an association equilibrium..."

98. Frank, H. S., and Thompson, P. T.: A Point of View on Ion Clouds. Ch. 8 in The Structure of Electrolytic Solutions. John Wiley & Sons, New York (1959).

"After thirty years no one has yet succeeded in using, or in modifying, the DH theory in a way which is able to give an exact account of activity coeffs., or of heats of dilution, in real solns. without employing parameters which not only are empirical but also take on numerical values which are often markedly peculiar." See Frank and Tsao, *Ann. Rev. Phys. Chem.* 5, 43 (1954).

F. and T. present a "diffuse-lattice" picture as an interpretation of data at higher concentrations.

99. Frank, H. S., and Thompson, P. T.: Fluctuations and the limit of validity of the Debye-Hückel theory. *J. Chem. Phys.* 31, 1086-1095 (1959).

"An equation derived by Fowler and by Kirkwood has the general form of the PB eqn. of the DH theory, but shows the latter to fall short of rigorous correctness through omission of two terms proportional, respectively, to the part played by a cloud ion in inducing charge density and to the sum of the mean-square fluctuations of the components of field strength. It seems likely that these correction terms would disappear or cancel for the case of an infinitely fine-grained ion cloud in an idealized continuous-dielectric solvent. By proceeding on this hint, it is shown that the equations of the DH theory contain within them the implication that ψ , ρ , E , etc. are non-fluctuating and that the DH ion cloud does in fact approach infinite fine-grainedness in an appropriate sense as infinite dilution is approached. The theory, and the equations to which it leads, can thus be interpreted as being rigorously correct in the limit of infinite dilution but only in this limit. As conc. increases, failure of fine-grainedness begins to introduce errors into the equations and it is concluded that these become catastrophic and lead to a breakdown of the DH formalism at a conc. c_0 , where the thickness of the ion cloud $1/\kappa$ equals \bar{l} , an average distance apart of nearest-neighbor ions. For 1-1 solutes in water at 25° C, $c_0 \approx 10^{-3}$ moles/l, and for higher valence types, or lower dielectric constants, it is still smaller. These results may be paraphrased by the statement that the DH theory is a theory of long-range interactions and fails when nearest-neighbor interactions begin to dominate. The suggestion emerges that for $\bar{c} > c_0$ the electrostatic behavior of the ion cloud may be related to l as a characteristic length. This suggestion receives support from the observed fact that $\log f_{\pm}$ seems typically to be linear in $c^{1/3}$ in the conc. range just above c_0 ."

100. Frenkel, J., and Finkelstein, B.: Über den Einfluss der Ionengrösse auf die Zustandsgleichung starker Elektrolyte. *Z. Physik.* 35, 239-242 (1925).

An equation similar to that of van der Waals is proposed. "Es sei bemerkt, dass bei Debye und Hückel der Übergang zu den höheren Konzentrationen auch durch die Einführung der endlichen Dimensionen der Ionen ermöglicht wird; die Art aber, in welcher dies Platz greift,

scheint uns sehr künstlich und logisch unzutreffend zu sein." See also PA 29, 275 (1926).

101. Friedman, H. L.: On Mayer's ionic solution theory. *Molecular Phys.* 2, 23-38 (1959).

"This theory, which is based upon McMillan and Mayer's cluster expansion of the grand partition function, is extended to include all of the components of the potentials of average force between sets of solute molecules or ions in the solvent at infinite dilution. The resulting cluster integral sum, which is a sum of integrals over an infinite number of infinite series of Mayer prototype graphs, is transformed into the sum of a single infinite series of integrals on graphs involving new types of bonds. These bonds are defined in a way first suggested by Meeron (1957, 1958). There results a compact expression for the cluster integral sum." See Mayer (1950), Haga (1953), Poirier (1953). Similar results were obtained by Abe (1959).

102. Friedman, H. L.: The singularities of the integrals in Mayer's ionic solution theory. *Molecular Phys.* 2, 190-205, errata 436 (1959).

"The terms of the expression previously obtained by Friedman (see above ref.) for the cluster integral sum in Mayer's theory are examined as to order in total ion conc., c , at the limit $c = 0$. The order of the singularity at $c = 0$ is calcd. for several of those terms of the irreducible cluster integrals that correspond to graphs of low connectivity but with an arbitrary number of vertices. On the basis of these calcs. and two postulates concerning the relation of the singularities of these integrals to others, it is concluded that the terms of the cluster integral sum, when arranged in order of increasing index, are also in increasing order of conc., and that the first term, $\kappa^3/12\pi$, has a lower order than any other. The order in conc. of the higher terms depends on whether the third moment of the conc. of charge types, $\sum c_S z_S^3$, vanishes, as it does in solns. of electrolytes of symmetrical charge type."

103. Friedman, H. L.: Mayer's ionic solution theory applied to electrolyte mixtures. *J. Chem. Phys.* 32, 1134-1149 (1960).

"For solns. of a mixture of two electrolytes with a common ion, the characteristic free energy function is $\Delta_m G^{\text{ex}}$, the change in excess free energy on forming the solution from solutions of the single electrolytes. This is closely related to $\Delta_m \mathcal{G}$, where \mathcal{G} is the cluster integral sum of the Mayer theory..."

104. Friedman, H. L.: Thermodynamic excess functions for electrolyte solutions. *J. Chem. Phys.* 32, 1351-1362 (1960).

"A system of excess functions is developed for electrolyte solutions and other solutions with an essentially unsymmetrical solvent-solute relation. These new functions vanish for a solution whose practical (molal scale) osmotic coefficient is unity at all compositions, temperatures, and pressures. The use of these excess functions offers some advantages over other methods of comparing Mayer's ionic solution theory with experiment..."

105. Fuchs, K., Kynch, G. J., and Peierls, R.: The equation of state of air at high temperatures. British Ministry of Supply Report MS-61 (BM-83) (1942); declassified and issued by USAEC OTS as Report OTI-57.

"Bethe has calculated the properties of air between 5000° and 25,000°, the range in which some fraction of the molecules has dissociated, and ionization of the atoms has begun. The aim of this report is to extend these calcs. to much higher temperatures, up to 2×10^6 degrees. At the highest temperatures the atoms are stripped of the orbital electrons... we assume that air is a mixture of 21% oxygen and 79% nitrogen... The treatment divides naturally into two parts: Part I. The calc. of the partition functions of the assembly of possible constituents of the mixture at high temperatures. The gas consists of oxygen and nitrogen atoms in various stages of ionization, together with a number of free electrons, and we shall calculate the p.f.'s of each component allowing for interactions. Part II: Assuming thermal equilibrium, we calc. the fraction of atoms of each type and the number of electrons present, for a number of different temperatures. The p.f. of the mixture is then obtained, and from this are deduced its various properties, including the free energy, the entropy, and the pressure." The interaction between charges in different parts of the system are neglected.

This investigation was the forerunner of many later calcs. using high-speed computers -- see Hilsenrath et al. (1955, 1958, 1959); Hirschfelder and Curtiss (1948); Gilmore (1955), etc.

106. Fukuda, N.: A new approach to the many-body problem, in particular to the theory of the electron gas. *Physica* 26, S162-169 (1960).

Explores the analogy with meson pair theory suggested by Sawada and Wentzel, but does not obtain any explicit results.

107. Fukuda, N., and Wada, Y.: Some aspects of many-body problem, *Progr. Theoret. Phys. (Kyoto) Suppl. No. 15*, 61-139 (1960).

Review of quantum theory of the electron gas.

108. Fuoss, R. M.: Influence of dipole fields between solute molecules. I. On osmotic properties. *J. Am. Chem. Soc.* 56, 1027-1030 (1934).

"If we consider electrolytic solutions in solvents of various dielectric constants, we first find, as the dielectric constant decreases, an increasing tendency for the formation of ion pairs... [We] calc. ... the osmotic properties of electrolytes in solvents of low dielectric constant ... using an ellipsoidal model to represent the solute particles."

109. Fuoss, R. M.: Distribution of ions in electrolytic solutions. *Trans. Faraday Soc.* 30, 967-980 (1934).

Discussion of ion association, definition of ion pairs and calc. of their distribution function.

110. Fuoss, R. M.: Two theorems concerning electrolytes. J. Chem. Phys. 2, 818-821 (1934).

"Fluctuations in the average total electrostatic energy E of the free ions of an electrolytic solution as calculated by the theory of Debye and Hückel are negligibly small in accessible conc. ranges.... (2) A general relationship connecting free energy F and average electrostatic energy E is derived; for the case where the average potential around an ion is given by the DH formula, $F = 2\bar{E}/3$."

111. Fuoss, R. M., and Kraus, C. A.: Properties of electrolytic solutions. XV. Thermodynamic properties of very weak electrolytes. J. Am. Chem. Soc. 57, 1-4 (1935).

"It is the purpose of this paper to extend a previous treatment [ibid. 56, 1027] of the osmotic properties of dipole solutes and to apply the results to experimental data..." (It is assumed that the ions are associated in pairs to form dipoles.)

112. Fuoss, R. M., and Accascina, F.: Electrolytic Conductance. Interscience Publishers, New York (1959).

P. 6, comments on Milner (1912) theory. P. 101 ff., DH theory.

113. Gerasimović, B. P.: Über das Ionisierungsgleichgewicht eines lumineszierenden Atomsystems. Z. Physik. 39, 361-376 (1926).

"Es ergibt sich eine Formel des Ionisierungsgleichgewichts, welche für den Fall des thermodynamischen Gleichgewichts in die bekannte Sahasche Formel übergeht." See Saha (1920).

114. Ghosh, J. C.: The abnormality of strong electrolytes. Part I. Electrical conductivity of aqueous salt solutions. J. Chem. Soc. 113, 449-458 (1918).

Attempts to calc. the number of free ions from the kinetic theory using Boltzmann factor with a "work of dilution" which he takes to be

$$U_e = -(Ne^2/D)(2N/V)^{1/3}$$

where D = dielectric constant and $(V/2N)^{1/3}$ is the mean distance between two ions. For criticism of Ghosh's theory see Falkenhagen (1932) §24. Cf. Malmström (1905).

115. Ghosh, J. C.: The abnormality of strong electrolytes. Part III. The osmotic pressure of salt solutions and equilibrium between electrolytes. J. Chem. Soc. 113, 707-715 (1918).

Uses Clausius' virial theorem to evaluate the effect of interionic forces on the osmotic pressure. He obtained the result

$$\frac{PV}{RT} = n(1 - A\gamma^{1/3}), \quad \gamma = \text{conc.}$$

whereas the correct limiting law from the DH theory is

$$\frac{PV}{RT} = n(1 - \gamma^{1/2}).$$

116. Gilmore, F. R.: Equilibrium composition and thermodynamic properties of air to 24,000°K. RAND Report RM-1543 (1955).

"Previous calcs. of the high-temperature thermodynamic properties of air are inaccurate because they use the old low value for the dissociation energy of nitrogen, or inadequate because they cover only a narrow density range. The present paper reports results for the composition, pressure, energy and entropy of dry air at eleven temperatures between 1000 and 24,000°K and eight densities between 10^{-6} and 10 times normal density. The calculations assume an ideal gas mixture in chemical equilibrium, including dissociation and ionization. . . . The ideal-gas internal energies and free energies of 29 different molecules, atoms and ions, which were evaluated at various temperatures are also reported. In addition, the fractions of the diatomic molecules in each electronic state are tabulated. Hugoniot (shock wave) curves for air at various initial densities are also included."

117. Glassgold, A.: The theory of the electron gas. Lawrence Radiation Lab. (Berkeley) Rept. UCRL 9228 (1960). Lecture notes from a course at the University of California, Berkeley.

Ground state energy; ring diagrams, exchange terms; Sawada's Hamiltonian method; particle-hole method.

118. Glauber, A. E.: K teorii sistem elektricheskii zaryashennykh chastits. Doklady Akad. Nauk S.S.S.R. 78, 883-885 (1951). UCRL Trans. 666(L).

The modified Coulomb potential $(e_a e_b / \epsilon r)(1 - e^{-ar})$ is used to calculate the pair distribution function following Bogolyubov's method (1946). ϵ = dielectric constant.

119. Glauber, A. E., and Yukhnovskii, I. P.: K statisticheskoi teorii kontsentrirrovannykh rastvorov sil'nykh elektrolitov. I, II. Zhur. Eksptl. i Teoret. Fiz. 22, 562-578 (1952). UCRL Trans. 667(L).

"Inclusion of the dielectric constant of the solvent in the law of interaction [see Glauber 1951] takes account of the solvent. Math. difficulties are removed by including the interaction potential, which accounts for repulsive forces quantitatively but does not contain the Coulomb term for small interionic distances. A general formula for binary distributions is found, and for the zero approx. the dependence on conc. is discussed. II. A formula is derived that for very weak concs. goes over into the Debye law. . . ." -- PA 56, 95 (1953), CA 49, 11366 (1955). The results of this paper are discussed by Falkenhagen and Kelbg (1959), and by Kessler and Gorbanev (1958). See criticism by Bazarov (1957) and reply by Yukhnovskii (1958); also Vedenov (1959), Vedenov and Larkin (1959).

120. Glauber, A. E.: Kinetic theory of a system of interacting particles. Associated Tech. Serv. Translation ATS-RJ 546; Zhur. Eksptl. i Teoret. Fiz. 25, 560-570 (1953).

Extension of his previous paper (Glauber 1951).

121. Glauber, A. E., and Yukhnovskii, I. P.: O 'Superpozitsionnoi' approksimatsii v teorii sistem vzaiomdeistvuyushikh chastits. Doklady Akad. Nauk S.S.S.R. 93, 999-1002 (1953). UCRL Trans. 668(L).
 "On the 'superposition' approx. in the theory of systems of interacting particles."
 Gorbanev, A. I.: see Kessler, Y. M.
122. Green, H. S.: Equations of state of metal plasmas. NAVWEPS Report 7073; NOTS TP 2478 (1960).
 "In the high-temp. metal gas, the method of Yvon-Kirkwood-Born-Green, as developed by Yvon for the Coulomb interaction case, is modified to take account of quantum corrections." See ref. 342.
 Green, M. S.: see Beckett, C. W.; Hilsenrath, J.
123. Gronwall, T. H., and La Mer, V. K.: On the extension of the Debye-Hückel theory of strong electrolytes to concentrated solutions. Science 64, 122 (1926).
 Preliminary announcement of results (see below) with no details of the mathematical method employed. Hückel's results (1925) are said to be invalid because of "a faulty application of the so-called charging process" leading to an erroneous expression for the electrostatic free energy term.
124. Gronwall, T. H.: On the determination of the apparent diameters of the ions in the Debye-Hückel theory of strong electrolytes. Proc. Natl. Acad. Sci. U. S. 13, 198-202 (1927).
 In previous applications of the DH theory [Schärer, Physik. Z. 25, 145 (1924); La Mer et al., J. Am. Chem. Soc. 49, 363 (1927); La Mer and Mason, *ibid.* 49, 410 (1927)] the apparent diameters came out negative in some cases. "It is the purpose of the present note to show that satisfactory values of the apparent diameters result from the DH theory, without any additional hypothesis, by returning to the unabridged form of the DH fundamental equation..."
125. Gronwall, T. H., La Mer, V. K., and Sandved, K.: Über den Einfluss der sogenannten höheren Glieder in der Debye-Hückelschen Theorie der Lösungen starker Elektrolyte. Physik. Z. 29, 358-393 (1928).
 "...an analytical integration process is developed [for Poisson's equation] which regards the complete static expression of the electric density as a function of ψ [electrostatic potential] instead of replacing the density by its first linear function in ψ as is done in the DH approx. calc. From this, the free energy and also the activity coeffs. are obtained in the form of infinite series which proceed according to powers of $1/D$, where D is the dielectric constant. With very small concs. asymptotic expressions are obtained, so that Debye's limiting law holds generally, and not merely on the basis of the Debye approximation. For the symmetrical case (ions in pairs of equal valency) the infinite series referred to above are investigated analytically as far as the term in $1/D^5$, and

their values tabulated. Comparison of the formulae with the experimental data exhibits good agreement, even in cases of small ionic diameters, in which Debye's approximation fails." -- T. H. Pope, PA 31, 829 (1928). Cf. Onsager (1933); Guggenheim (1959).

126. Gross, P., and Halpern, O.: Über temperaturabhängige Parameter in der Statistik und die Debyeschen Elektrolyttheorie. Physik. Z. 26, 403-407 (1925).
Thermodynamic discussion. Effect of temperature-dependence of the dielectric constant on calc. of the electrostatic and free energy in DH theory.
127. Guernsey, R. L.: The Kinetic Theory of Fully Ionized Gases. Dissertation, University of Michigan (1960); issued as Tech. Rept. 03114.
Part I: Equilibrium theory. Review of DH theory, Mayer's cluster expansion and summation of diagrams, distribution functions and explicit calc. of S_2 (cf. Abe 1959) for hard spheres with Coulomb interactions. Discussion of Bogolyubov's method (1946) and its application to Coulomb forces.
128. Guggenheim, E. A.: The specific thermodynamic properties of aqueous solutions of strong electrolytes. Phil. Mag. (series 7) 19, 588-643 (1935).
Limiting form of activity coeffs. at ∞ dilution; limitations and variations of DH treatment; proposals for comparison of thermodynamic properties of real solutions of electrolytes with an imaginary one which accurately obeys the DH formula with a definite radius ($a = 3.08$). An approx. to DH theory for higher concs. is introduced, based on Brönsted's assumption that there is no "specific interaction" between ions with the same sign.
129. Guggenheim, E. A.: Ion distribution in dilute aqueous solutions of single binary electrolytes. Discussions Faraday Soc. 24, 53-65 (1957).
"The app. of the DH model ... to 1:1 and 2:2 electrolytes is re-examined. The solns. of the PB differential equation by the DH approx. and by the Müller method of numerical integration are compared..." -- M. Allen, CA 53, 10913 (1959).
130. Guggenheim, E. A.: The accurate numerical solution of the Poisson-Boltzmann equation. Trans. Faraday Soc. 55, 1714-1724 (1959).
The PB equation formulated by DH has been accurately solved numerically and the result compared with the solution in series obtained by Gronwall. The integrations are done for 1-1, 2-2, 2-1, and 3-1 electrolytes; all relate to $s/a = 1.75$ (in water at 0° C the value of s is 6.94 Å and the corresponding value of a is 3.96 Å). Here s = distance at which the mutual electrostatic energy of a pair of singly charged ions is equal to kT ; $s = e^2/\epsilon kT$ where ϵ is the permittivity of the soln.
131. Guggenheim, E. A.: Activity coefficients and osmotic coefficients of 2:2 electrolytes. Trans. Faraday Soc. 56, 1153-1158 (1960).

"Theoretical values of activity coeffs. and osmotic coeffs. of 2:2 electrolytes in dilute solns. have been evaluated by accurate numerical integration of the PB eqn. [See above.] It is well established that the PB eqn. itself contains an internal inconsistency ... [hence] different values are obtained for the contributions of the ionic interactions to the thermodynamic functions according to the sequence in which we visualize the charging process. In the present paper the implied charging process has been of one ion at a time and this leads to formula (2.1) first proposed by Guntelberg." (see Bjerrum 1926.)

Guggenheim, E. A.: see also Fowler, R. H.

Haar, L.: see Beckett, C. W.

132. Haga, E.: On Mayer's theory of dilute ionic solutions. *J. Phys. Soc. Japan* 8, 714-723 (1953).

"Explicit expressions for the logarithms of activity coeff. of dilute ionic solns. right up to $c^{3/2}$ and for the osmotic pressure right up to $c^{5/2}$ are calculated according to Mayer's theory by the use of Fourier transformation. The two prototypes [graphs] which Mayer supposed, by his rough evaluations, to lead to terms of higher order are proved to be included in the present approximation. Calcd. osmotic coeffs. for 1-1 electrolytes are compared with experimental values, yielding to mean ionic diameters values which are more reasonable than in DH's theory."

See also Meeron (1957, 1958, 1959), Friedman (1959, 1960), and Abe (1959).

133. Halpern, O.: On the statistical basis of the theory of electrolytes. *J. Chem. Phys.* 2, 85-93 (1934).

"... investigates how far the various statistical-thermodynamical methods hitherto proposed are suitable for application to strong electrolytes. The significance of the ionic radius is, in many instances, far more important than has hitherto been assumed. When the influence of the ionic radius is negligible, conditions are derived from dimensional considerations which considerably restrict the functional form of the free energy. Furthermore, proceeding from conditions of integrability, thermodynamics appreciably limits the number of possible expressions for the ionic potential. The disregarding of these limitations has been responsible for certain paradoxes in the literature on this subject. A new fluctuation formula for the electric potential of the ions is derived and conclusions are drawn from it as to the correctness of existing theories. In connection with this last a deduction proposed by Fowler (1929) is reviewed. Kramers' theory of electrolytes (1926) is tested with respect to its agreement with the theorems here developed. Finally, a review of the statistical and thermodynamical basis of Bjerrum's theory of ionic association (1926) is presented. ... Contrary to general opinion, it is impossible by a reduction of conc. always to reach a region in which the limiting law holds. While the Debye theory as extended by Gronwall, La Mer, and Sandved (1928) permits to do so, though for media of low dielectric constant only at low concs. without physical interest, the consideration of the fluctuation terms excludes this possibility. There would be nothing like a

limiting law in water either if the ionic dimensions happened to be, let us say, one-fiftieth of their actual value." Bjerrum's method is considered invalid because of the long range of the Coulomb forces. The work of P. van Rysselberghe (1933) is also criticized. The conclusion of Kramers, that one can always find a conc. at which the free energy is independent of ionic radius, is denied.

Halpern, O.: see also Gross, P.

134. Hamer, W. J.: The Structure of Electrolytic Solutions. John Wiley & Sons, New York (1959).

Ch. I. Review of early history of the theory of electrolytic solns.

135. Hansen, C. F., and Heims, S. P.: A review of the thermodynamic, transport, and chemical reaction rate properties of high-temperature air. Natl. Advisory Comm. Aeronaut. Tech. Note 4359 (1958).
136. *Hansen, C. F.: Approximations for the thermodynamic and transport properties of high temperature air. NASA-TR-R-50 (1959) (Supersedes NACA-TN-4150).

Compressibility, enthalpy, entropy, specific heat, etc. for temps. from 500 to 15,000°K, pressures from 0.0001 to 100 atm.

137. Harned, H. S., and Owen, B. B.: The Physical Chemistry of Electrolytic Solutions. Reinhold Publ. Corp., New York (1943). Third edition, 1958.

Ch. 2. General statement of the interionic attraction theory and properties of ionic atmospheres. Ch. 3. Theory of thermodynamic properties of aqueous solutions. Ch. 5. Numerical compilations of physical constants, characteristic slopes, and mathematical functions.

138. Harris, G. M.: Equilibrium properties of a multicomponent ionized gas. J. Chem. Phys. 31, 1211-1220 (1959).

"A method has been developed for the calc. of the equilibrium properties of an ionized gas consisting of many nuclear and molecular species. An essential feature of the present calc. is that it explicitly considers more than one ionic species per atom and therefore applies to partially ionized atoms and molecules. Free and bound electrons are distinguished by counting as bound electrons all those in the ground state of each ionic species. Molecular species with internal degrees of freedom are also included. The additivity of kinetic and potential energy is assumed, a classical electrostatic potential of interaction is used, and electron degeneracy is included only in the kinetic energy terms. The Helmholtz free energy of the system is minimized with respect to the conc. of each species assumed present, thus determining the equilibrium composition of the system as a function of temperature and volume. The thermodynamic quantities of interest are then calcd. for an appropriate temperature-volume grid. This method thus allows the effect of the variation of composition on the equation of state to be determined, as well as the delineation of regions in PVT space where the electron

degeneracy and electrostatic interaction each become important. The present model is applied to a system of particles arising from the hydrogen molecules."

139. Harris, G. M., Roberts, J. E., and Trulio, J. G.: Equilibrium properties of a partially ionized plasma. *Phys. Rev.* 119, 1832-1841 (1960).
- "...the model described here is in part an improved version of an earlier model" (Harris 1959). "The Coulomb interaction is treated in the classical Debye approx. However, a distance of closest approach between ions and electrons depending on the kinetic energy of the electrons is included to avoid the short-range divergence of the Coulomb potential. The kinetic energy of the free electrons is calcd. from the p.f. for a perfect Fermi gas. The vibrational and rotational motion are treated in the harmonic oscillator and rigid rotor approx. with the number of energy levels counted for a given electronic state depending on the dissociation energy of the state. A volume dependence of the bound electronic energy eigenvalues is included by considering the effect of surrounding particles as a confinement of a given particle to a spherical box of variable size..."
- 139a. Harris, G. M., and Trulio, J. G.: Equilibrium properties of a partially ionized plasma. *J. Nuclear Energy (Part C)* 2, 224-234 (1961).
- Earlier version of the above paper.
140. Harris, G. M.: Attractive two-body interactions in plasmas. UCRL-6486; *Phys. Rev.* (in Press).
- Effect of Debye shielding on bound states of hydrogen atom. cf. ref. 346.
- Hartley, H.: see Nonhebel, G.
- Heine, V.: see Falicov, L. M.
141. Hill, T. L.: An introduction to statistical thermodynamics. Addison-Wesley Publ. Co., Reading (1960).
- Ch. 18: "Dilute Electrolyte Solutions and Plasmas." Discussion of DH theory and a paper of Kirkwood, *J. Chem. Phys.* 3, 300 (1935).
142. Hilsenrath, J., and Beckett, C. W.: Thermodynamic properties of argon-free air (0.78847 N₂, 0.21153 O₂) to 15,000° K. *Natl. Bur. Standards (U.S.) Rept.* 3991 (1955).
- "The thermodynamic properties ... are given for equilibrium mixtures of dissociated and ionized molecules and atoms of the elements nitrogen and oxygen."
143. Hilsenrath, J., and Wegstein, J. H.: Mechanized Computation of Thermodynamic Tables at the National Bureau of Standards. P. 79-90 in Proc. Conference on Thermodynamic and Transport Properties of Fluids, London, 1957. Inst. of Mechanical Engineers, London (1958).
144. Hilsenrath, J., Green, M. S., and Beckett, C. W.: Internal energy of highly ionized gases. Proc. 9th International Astronautical Congress,

Amsterdam, 1958, p. 120-136. Springer Verlag, Vienna (1959).

"A method is described for the computation of certain thermodynamic properties of gases and gas mixtures containing atoms and atomic ions in chemical equilibrium.... The computation ... is well suited to desk calculations The inclusion of DH effects on the thermodynamic properties complicates even this simple method to such an extent as to make hand computation over an extended range of points exceedingly laborious. The methods for including these corrections are, however, quite suitable for digital computers."

145. Hilsenrath, J., Klein, M., and Sumida, D. Y.: Mechanized computation of thermodynamic tables at the National Bureau of Standards: The calculation of the equilibrium composition and thermodynamic properties of dissociated and ionized gaseous systems. P. 416-437 in Thermodynamic and Transport Properties of Gases, Liquids, and Solids.

McGraw-Hill Book Co., New York (1959).

"A high speed computing method is described for the solution of the non-linear equations defining chemical equilibria in homogeneous gaseous reactions.... An appendix to the paper gives an indexed bibliography of [45] compilations of ideal gas thermal functions for the elements, and their oxides, hydrides, borides, carbides, fluorides and nitrides."

The effect of Coulomb interactions on the pressure is not considered.

146. Hirschfelder, J. O., and Magee, J. L.: Thermodynamic properties of air at high temperatures. Los Alamos declassified report, LADC 122.
147. Hirschfelder, J. O., and Curtiss, C. F.: Thermodynamic properties of air, II. Univ. Wisconsin Report APL/JHU-CM-518 (1948).

"The thermodynamic properties of air have been computed over a temperature range from 273°K to 5000°K at 100° intervals and at six densities ranging from 0.008 to 25 times the normal density.... The dissociative reactions which occur at high temperatures have been considered.... Complete tables of chemical composition are included.... In addition to the basic tables, the thermodynamic properties are given along adiabats. The Riemann characteristic and shock front conditions are tabulated.... It is sufficiently accurate to use the virial form of the equation of state, considering only the second virial coeff...."

148. Hubbard, J.: The description of collective motions in terms of many-body perturbation theory. II. The correlation energy of a free-electron gas. Proc. Roy. Soc. (London) 243, 336-352 (1957).

The theory developed in a previous paper (ibid. 240, 539) is applied to the calc. of the correlation energy; the results are similar to those of Pines (1953).

149. Hückel, E.: Zur Theorie der Elektrolyte. Ergeb. exakt. Naturw. 3, 199-276 (1924).

Review article. Part I: "Thermodynamische Erscheinungen. (1) Die osmotische Zustandsgleichung starker Elektrolyte für kleine Konzentration. (2) Allgemeine thermodynamische Grundlagen. (3) Theoretische und Experimentelles über die Aktivitätskoeffizienten starker Elektrolyte bei kleinen Konzentrationen..."

150. Hückel, E.: Zur Theorie konzentrierter Wässriger Lösungen starker Elektrolyte. *Physik. Z.* 26, 93-147 (1925).
Application of the DH theory with correction for ionic size, comparison with experiments. Criticized by Gronwall and La Mer (1926).
151. Hückel, E., and Krafft, G.: Untersuchungen über den Einfluss der endlichen Ionengrößen auf das thermodynamische Verhalten von Elektrolytlösungen. *Z. physik. Chem. (Frankfurt)* 3, 135-175 (1955).
"Previous authors [Wicke and Eigen (1951, 1952, 1953); Falkenhagen and Kelbg (1952), etc.] tried to extend to higher concs. the range of validity of Debye's theory ... by taking into account the spatial hindrance between the ions within the ion atmospheres to explain theoretically the increase of activity as a function of the electrolyte conc. By aid of a statistical method due to Kirkwood (1934) for the calc. of the free energy of an electrolyte soln., Hückel and Krafft try to show that the deductions given by the previous authors, and hence also the conclusions drawn therefrom, are incorrect." -- F. Epstein, *CA* 49, 8670 (1955).
See reply by Schlögl (1955) and by Wicke and Eigen (1955), and rejoinder by Hückel and Krafft (next reference).
152. Hückel, E., and Krafft, G.: Notiz zu der Bemerkung von Wicke und Eigen und der Erwiderung von Schlögl betreffend unsere Arbeit "Untersuchungen über den Einfluss der endlichen Ionengrößen usw." *Z. physik. Chem. (Frankfurt)* 5, 305-311 (1955).
See Wicke and Eigen (1955) and Schlögl (1955).
Hückel, E.: see also Debye, P.
153. Ichikawa, Y. H.: Equilibrium properties of classical electron gas in uniform positive ion distribution. *Progr. Theoret. Phys. (Kyoto)* 20, 715-727 (1958).
"Thermal equilibrium properties of a classical electron gas are investigated by taking into account the plasma oscillation mode. The free energy is calcd. in terms of collective coordinate representation. It is shown explicitly that the DH limiting term of the free energy is due to short range correlation part of the Coulomb interaction, and that the long range correlation effect increases the free energy by 22% of the DH term."
Cf. Abe (1959).
Iukhnovskii, I. R.: see Yukhnovskii, I. R.
154. Iwata, G.: Applications of Mellin transforms to some problems of statistical mechanics. *Progr. Theoret. Phys. (Kyoto)* 24, 1118-1120 (1960).

Gives a short derivation of a series expansion for Abe's S_2 integral (see Abe 1959) for a one-component electron gas.

155. Kaeppler, H. J., and Baumann, G.: Irreversible stochastic thermodynamics and the transport phenomena in a reacting plasma. AFOSR-TR-57-20; ASTIA Document AD-120 462 (1956); AF-61(514)-939-1956. Mitteilungen aus dem Forschungsinstitut für Physik der Strahlentriebe E. V. Verlag Flugtechnik/Ernst von Olnhausen, Stuttgart (1956).

"... a first venture in attempting a theory of transport phenomena in a reacting plasma at elevated and high temperatures. As an essential basis for such studies, the equilibrium behavior of a plasma is treated. These equilibrium considerations concern the influence of electrostatic microfields on plasma properties, termination of the electronic partition function, and determination of the plasma composition..."

Kelbg, G.: see Falkenhagen, H.

156. Keller, G., and Meyerott, R. E.: The ionization of gas mixtures in stellar interiors. ANL-4771 (1952).

"A statistical theory of the ionization of heavy atoms in a gas mixture is proposed. Approximations have been made for a mixture which is very rich in hydrogen and helium and for which the temperature is high enough so that these elements are completely ionized, as is the case throughout most of the interior of a star. Contrary to Morse's method (Astrophys. J. 92, 27 (1940)) the hydrogen and helium nuclei surrounding a particular heavy nucleus (whose ionization potential is being studied) are not assumed to be separated by certain minimum distances as determined by the radii of their 'ion spheres.' Instead the surrounding nuclei are assumed to be, like the electrons, distributed statistically, as in the DH theory of strong electrolytes. It is found that the average electrical potential near a heavy ion obeys a generalized TF equation, and it is shown that under the physical assumptions made above the exact solutions of the equation are sufficiently self-consistent. It is pointed out that when ionization occurs the new free electron does not effectively go to infinite distances but instead joins the free electron shield around the ion. Consequently, both the effective ionization energy and the statistical weight of the states of the surrounding gas are affected."

157. Keller, G., and Meyerott, R. E.: The ionization of gas mixtures in stellar interiors. II. The average number of electrons occupying various shells. ANL-4856 (1952).

158. Keller, J. B.: Electrohydrodynamics. I. The equilibrium of a charged gas in a container. J. Rat. Mech. Anal. 5, 715-724 (1956).

"... theory of equilibrium of a uniformly charged gas in a perfectly conducting rigid container. The equilibrium is established when the electric forces in the gas must balance the pressure forces. He demonstrates that the density inside the container does not increase

indefinitely with mass. Instead, at each inner point the density has an upper bound which depends on the shape of the container and the location of the point. As the point approaches the boundary, the bound increases indefinitely. Thus, as the mass of the gas increases, most of the gas accumulates in a thin layer near the surface. The author points out the interesting practical consequence of this fact -- namely that the density of a charged gas cannot be made arbitrarily large inside a container by putting more gas into it." --A. K. Oppenheim and R. R. Hughes, *Ind. Eng. Chem.* 49, 590 (1957).

A real gas composed of particles whose total charge is not zero does not have an "equation of state" in the usual sense; hence all the other investigations of "one-component" electron gases listed in this bibliography postulate some kind of oppositely-charged background to make the system electrically neutral. Keller describes what would happen if this background were not present. References to earlier mathematical work on the corresponding one-component PB equation are given by M. von Laue, *Jahrb. Radioakt.* 15, 205 (1918).

Kerney, K. P.: see Covert, E. E.

159. Kessler, Y. M., and Gorbanev, A. I.: Note on Glauber and Yukhnovskii's equation. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk* 1010-1011 (1958); *Bull. Acad. Sci. U.S.S.R., Div. Chem. Sci. S.S.R. (English Translation)* 981-982 (1958).

"The error in the Glauber-Yukhnovskii equation (1952) for the electrostatic quantity of free energy in a soln. of an electrolyte was corrected." -- J. R. Leach, *CA* 53, 5833 (1959).

160. Kessler, Y. M., and Gorbanev, A. E.: Note on the theory of solutions of strong electrolytes. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk* 2116-2118 (1959); *Bull. Acad. Sci. U.S.S.R., Div. Chem. Sci. S.S.R. (English Translation)* 2019-2021 (1959).

Review of various proposed corrections to DH theory. To obtain agreement with experiment one cannot assume an increase in ionic diameter and hydration number with temp.; it is necessary to consider existence of ionic pairs and changes in structure of the solution with conc.

161. Kidder, R. E., and DeWitt, H. E.: Application of a modified Debye-Hückel theory to fully ionized gases. *J. Nuclear Energy (Part C)* 2, 218-223 (1961).

"The equations of the DH theory, modified to include quantum statistics, are discussed. It is found that the nonlinear equations used by Cowan and Kirkwood (1958) are not unique, and that the nonlinear theory can be formulated in different ways to give different answers. The linearized equations of these alternative formulations are discussed, and the correct form of the linearized theory is established. From the linear theory, the Helmholtz free energy of a slightly degenerate plasma is derived, and from this result, useful formulae in the near-classical limit are obtained for the pressure and internal energy."

King, M. F.: see Covert, E. E.

162. Kirkwood, J. G.: On the theory of strong electrolyte solutions. *J. Chem. Phys.* 2, 767-781 (1934).

"The nature of the approximations involved in the derivation of the PB eqn. of the DH theory is investigated in detail from the standpoint of classical statistical mechanics. The validity of the initial Debye approx., under the restrictions originally imposed upon it, is confirmed. Deviations arising from fluctuation terms and van der Waals forces are roughly estimated. An alternative to the Bjerrum method for the treatment of ions of small size and high valence is outlined.... The DH equation is statistically consistent with values of the fluctuation terms of the magnitude of the Gronwall-La Mer terms, and we believe to have presented convincing if not conclusive evidence that they cannot influence the initial Debye approximation."

According to Falkenhagen and Kelbg (1959), "The approximations upon which the Poisson equation rests are explicitly delineated for the first time" in this paper.

163. Kirkwood, J. G.: Statistical mechanics of fluid mixtures. *J. Chem. Phys.* 3, 300-313 (1935).

Integral equations for the potentials of mean force are derived by a "charging process," and in the case of Coulomb forces one of these equations yields as a solution the Debye shielded potential, from which the limiting laws of the DH theory may be derived.

Reviewed by Hill (1960); cf. Bogolyubov (1946).

164. Kirkwood, J. G., and Poirier, J. C.: The statistical mechanical basis of the Debye-Hückel theory of strong electrolytes. *J. Phys. Chem.* 58, 591-596 (1954).

"The potentials of mean force of sets of n ions, averaged over the configuration space of all other ions in the system, are expanded as power series in a charging parameter ξ . Equations are derived relating coefficients of the various powers of ξ in these expansions, using the method of semi-invariants. The validity of the linearized PB eqn. for the coeff. of the first power of ξ in the expansion of the potential of mean force of an ion pair, when ion size is neglected, is demonstrated. The validity of the DH limiting law is thus shown in an unambiguous way. A systematic procedure of obtaining the coeffs. of higher powers of ξ is outlined. When ion size is considered, the linearized integral eqn. for the potential of average force of a pair of ions possesses oscillating solutions at high ionic strength, corresponding to stratifications of average space charge of alternating sign in the neighborhood of each ion.... [Apropos of Mayer's theory (1950)] explicit proof that clusters corresponding to graphs of more complex topological types do not contribute terms of the same order as the limiting law is, to say the least, not transparent and obvious."

The results of this paper are summarized by Falkenhagen and Kelbg (1959).

Klein, M.: see Hilsenrath, J.

165. Klein, O.: Osmotic pressure of an electrolyte. Medd. Vetenskapsakad. Nobelinst. 5, No. 6, 1-9 (1919).
General discussion of effect of electrical forces on osmotic pressure.
See CA 14, 2572-2573 (1920).
166. Koppe, H.: Der Einfluss der Austauschenergie auf die spezifische Wärme des Elektronengases. Z. Naturforsch. 2a, 429-432 (1947).
"Es wird der Einfluss der durch die Antisymmetrisierung der Eigenfunktionen bedingten Austauschenergie auf die spezifische Wärme des Elektronengases untersucht. Es ergibt sich, dass, abgesehen von extrem kleinen Temperaturen, die Proportionalität von C_v zu T erhalten bleibt, nur ist der Proportionalitätsfaktor bis zu 50% kleiner als in der Sommerfeldschen Theorie."
See Wohlfarth (1950).
167. Kortüm, G., and Bockris, J. O'M.: Textbook of Electrochemistry. Elsevier Publ. Co., Amsterdam (1951), 2 vols. Based on Kortüm's Lehrbuch der Elektrochemie, 2nd German edition (1949).
Ch. V, Vol. I., p. 168-197: "Theory of Interionic Attraction."
Review of DH theory.
Krafft, G.: see Hückel, E.
168. Kramers, H. A.: Investigations on the free energy of a mixture of ions. Verslag Gewone Vergader. Afdel. Natuurk. Koninkl. Ned. Akad. Wetenschap. 35, 1153-1166 (1926); Proc. Acad. Sci. (Amsterdam) 30, 145-158 (1927); Collected Scientific Papers, North-Holland Publ. Co., Amsterdam (1956), p. 361-374.
Attempts a direct calc. of the p.f. using the modified Coulomb potential $(e^2/r)(1 - \exp[-\lambda r/2R])$, where R is the position of the center of mass of the two atoms whose distance of separation is r. This particular form is chosen so that "the property of the energy to be a homogeneous function of the coordinates of the degree -1 is preserved." The origin of coordinates is taken outside the container so that R is essentially constant. Conclusion: "A state of statistical distribution of the ions which is independent of the atomic radii and which is established if from the random distribution at very small concs. we pass to larger concs. can only be realized below a certain max. conc." Cf. Halpern (1934), Berlin and Montroll (1952)
169. Kraus, C. A.: Present state of the electrolyte problem. J. Chem. Educ. 35, 324-337 (1958).
Review.
170. Kroepelin, H., and Neumann, K. K.: Equilibria in a thermal plasma composed of C + H₂ and C + 2H₂ in a temperature range from 5000° K to 50,000° K at a total pressure of 1 Bar. Thermodynamic and Transport Properties of Gases, Liquids, and Solids, p. 453-464.

McGraw-Hill Book Co., New York (1959). Also: RAND translation T-99.

"The equilibria existing in the plasma may be calcd. according to the Eggert-Saha equation. However, it must be determined whether or not the ion density in the plasma reduces the ionization energy. . . . The plasma studied is composed of eight components (free electrons, neutral hydrogen atoms, neutral carbon atoms, protons, singly, doubly, triply and quadruply ionized carbon ions). . . . The individual members of the p. f. required in this work have been published by us in the Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft."

171. Kroepelin, H., and Winter, E.: Equilibria in $C + H_2$ and $C + 2H_2$ systems at temperatures between $1000^\circ K$ and $6000^\circ K$. Thermodynamic and Transport Properties of Gases, Liquids, and Solids, p. 438-452. McGraw-Hill Book Company, New York (1959). Also: RAND Translation T-100.

Effect of temperature and pressure on the state of equilibrium in the gas phase produced by decomposition of liquid hydrocarbons by an electric arc.

Kynch, G. J.: see Fuchs, K.

172. La Mer, V. K.: Recent advances in the ionization theory as applied to strong electrolytes. Trans. Am. Electrochem. Soc. 51, 507-555 (1927).

"The anomaly of strong electrolytes is reviewed from the classical view of incomplete dissociation, and from the modern view of practically complete dissociation and inter-ionic attractions, for which purpose the activity concept is developed. It is shown that the classical view must be abandoned, and that the mechanism of inter-ionic electrostatic attractions culminating in the theory of Debye and Hückel suffices as an explanation in dilute solns. A detailed presentation of this theory and a survey of experimental data designed to test the theory (some of which are presented for the first time) are given. The influence of the math. approx's. in the present form of the theory is shown to be most marked for ions of small size. This question and its relation to Bjerrum's hypothesis of ion-association is developed in some detail. Most of the discrepancies between theory and experiment vanish when the math. development is extended to include the case for ions of small size and high valence. A conversion table relating the values for the ion size obtained for the first approx. and the complete soln. for the symmetrical valence types is given. Brönsted's principle of specific interaction is discussed; also the question of the meaning of the true degree of dissociation of strong electrolytes."

La Mer, V. K.: see also Gronwall, T. H.

173. Landau, L. D., and Lifshitz, E. M.: Statistical Physics. (Translated by E. and R. F. Peierls) Pergamon Press, London (1958).

§74: "The completely ionized gas." DH theory, discussion of QM corrections, suggestion that higher correction terms could be found

by Bogolyubov's method (1946). 103: "Ionization Equilibrium."
104-108: "Properties of Matter at very high temperatures and
densities." Criticized by Vedenov (1959).

174. Larkin, A. I.: Thermodynamic functions of a low-temperature plasma.
Zhur. Eksptl. i Teoret. Fiz. 38, 1896-1898 (1960); Soviet Phys.
JETP 11, 1363-1364 (1960).

The equation of state is calcd. at temperatures below the ionization
temperature, taking into account the interaction of the ions with
the electrons of the continuous spectrum. (This compensates for
the divergence from the sum over bound states.) Abe's asymptotic
result (1959) is obtained together with some additional terms. See
also Vedenov and Larkin (1959).

Larkin, A. E.: see Vedenov, A. A.

175. Latter, R.: Equation of state of air on the statistical model. RAND
Report RM-1344-AEC (1954).

"An estimate of the eq. of state (for an oxygen, nitrogen and argon
mixture occurring in air) for the temp. range from 5000° K upward
and for densities from 1/200 to 50 times normal density. These
results are compared with those of Bethe, Fuchs, and others."

176. Lenard, A.: Exact statistical mechanics of a one-dimensional system
with Coulomb forces. MATT-64 (1961).
177. Leontovich, M.: Fluctuations of charge density in electrolytes. Compt.
rend. acad. sci. U.R.S.S. 53, 111-114 (1946).
See CA 41, 2649 (1947); Natanson (1946, 1951); Fisher (1952).
178. Levine, H. B.: Diagram expansions in quantum statistics. Phys.
Fluids 3, 225-245 (1960).

"The Montroll-Ward-Lee-Yang approach to quantum statistics is
generalized to multicomponent systems. It is also generalized so
as to include external fields. The formalism is constructed in a
volume-dependent manner, and includes internal coordinates, such
as spin, from the beginning. It is rigorously proved that the QM
volume-dependent cluster integral may be expressed in terms of
connected diagrams only. The rules for drawing these diagrams are
given..." See Montroll and Ward (1958), Lee and Yang, Phys. Rev.
113, 1165 (1959).

179. Levine, H. B.: Classification of diagrams for a plasma equation of
state. J. Nuclear Energy (Part C) 2, 206-217 (1961).

"Utilizing the Montroll-Ward approach to quantum statistics,
generalized to many components, we seek an equation of state for
a low density-high temperature plasma. We propose a classification
of diagrams analogous to that used by Friedman (1959) in classical
statistical mechanics. In the resulting expansion, the leading term
is the ideal gas contribution plus the lowest order exchange contri-
bution plus the ring contribution, the latter representing the effect
upon the pressure of collective motions of a completely ionized plasma.

The next term appears to represent a contribution due to modifications of free particle motion due to the interaction of the single particles with the rest of the plasma. The third term represents the contribution of two-particle states, both of positive energy between all particle pairs, and negative energy (bound states) between pairs of opposite charge sign. The third term also contains parts representing modifications of the motion of the pair of particles due to interaction of the individual particles with the rest of the plasma. Higher terms represent, successively, contributions of three-, four-, etc. particle states, again including modifications of the single particle motions. The classification automatically eliminates the ultraviolet catastrophe which ordinarily arises in the treatment of Coulomb force bound states in statistical mechanics, since, in effect, it uses a screened Coulomb potential instead of the ordinary potential. In addition, the short range divergence, which occurs in classical theory because of the 'fall' of the electron to the nucleus, does not arise, being prevented by the uncertainty principle."

180. Lietzke, M. H.: Tables of the activity coefficient of a 1-1 electrolyte and its derivative using a modified Debye-Hückel equation. ORNL-2628 (1958).

See Nuclear Sci. Abstr. 13, 359 (1959).

Lifshitz, E. M.: see Landau, L. D.

181. Lighthill, M. J.: Dynamics of a dissociating gas, Part I. J. Fluid Mech. 2, 1-32 (1957).

"The paper begins with a study of the equilibrium statistical thermodynamics of a pure dissociating gas. Here, an approx. is found which greatly simplifies the analysis and yet introduces only small errors for particular gases." The hypothetical "ideal dissociating gas" is characterized by three parameters, a characteristic temperature, density, and specific energy for dissociation. Gas imperfections are neglected, and a certain combination of the p.f.'s of the dissociated and undissociated molecules is assumed constant, an approx. shown to be fairly accurate for oxygen and nitrogen between 1000 and 7000° K.

Magee, J. L.: see Hirschfelder, J. O.

182. Malmstrom, R.: Versuch einer Theorie der elektrolytischen Dissociation unter Berücksichtigung der elektrischen Energie. Z. Elektrochem. 11, 797-809 (1905).

"Die elektrische Energie ist also proportional $n(n/v)^{1/3}E = kn^{4/3}v^{-1/3}$. Die Proportionalitätskonstante enthält im Zähler m^2 und in Nenner die Dielektrizitätskonstante."

Probably the first (but incorrect) attempt to estimate the effect of electrical interactions on the pressure of a mixture of ions. Cf. Ghosh (1918), Falkenhagen (1932, Ch. VI).

183. Martinek, F.: Thermodynamic and electrical properties of nitrogen at high temperatures. Thermodynamic and Transport Properties of

Gases, Liquids, and Solids, p. 130-156. McGraw-Hill Book Co., New York (1959).

"The basic thermodynamic properties of pure nitrogen at high temperatures are presented. Internal energy, enthalpy, entropy, electron density and electrical conductivity are given in engineering units for the temp. range from 5000° K to 30000° K and pressures varying from 0.2 atm to 100 atm. The temperature and pressure dependence of dissociation and ionization is also shown. All calcs. are based on statistical thermodynamics... The effect of the potential energy (Lennard-Jones) can be neglected for the temperatures and pressures considered in this paper. The equation of state for a perfect gas $PV = RT$ is then valid."

184. Mayer, J. E.: The theory of ionic solutions. *J. Chem. Phys.* 18, 1426-1436 (1950).

"The virial development for the osmotic pressure of a solution may be used, if the potentials of average force of the solute molecules at infinite dilution are known, to compute the deviations from perfect solution behavior. The expression for the logarithm of the activity coefficient can thus be obtained as a sum of coefficients multiplied by powers of the conc. For an ionic soln., with $1/R^2$ forces, the series is only conditionally convergent. By summing certain additive terms occurring in the coefficients over all powers of conc. convergence can be attained. The integrations necessary to obtain terms correct up to and including $c^{3/2}$ are performed. The results are given in terms of certain functions which can readily be computed."

This paper stimulated a large amount of theoretical research, of which we may mention Haga (1953), Meeron (1957, 1958), Friedman (1959), and Abe (1959). Similar results were obtained by Zubarev (1954), using collective variables, and by Bogolyubov (1946) and other Russian workers, using integral equations for the pair distribution function (cf. Kirkwood 1935).

McAulay, J.: see Debye, P.

185. McCrea, W. H.: On the equation of state of an ionized gas. *Proc. Cambridge Phil. Soc.* 26, 107-114 (1930).

Considers the problem of calculating the pressure when the number of various kinds of ions are known, without attempting to find the actual state of ionization for given temperature and pressure. It is shown that an ion consisting of several particles with large relative motions may nevertheless be treated as a single particle; in computing the kinetic ("dynamical") part of the pressure. The electrostatic correction is calcd. by the method of Eddington (1926, §182-188; 1928).

186. Meeron, E.: Mayer's treatment of ionic solutions. *J. Chem. Phys.* 26, 804-806 (1957).

"Mayer's expressions for the ionic activity coefficient and osmotic pressure of an electrolyte soln. are shown to involve known and accurately tabulated functions. Mayer's infinite series of integrals is summed to give a single integral involving the DH potential of

average force. With the help of the new form, the use of the single cut-off parameter for binary electrolytes is discussed from a quantitative standpoint." See Mayer (1950).

187. Meeron, E.: Theory of potentials of average force and radial distribution functions in ionic solutions. *J. Chem. Phys.* 28, 630-643 (1958).

"The procedure employed by Mayer (1950) for the calc. of osmotic pressure and activity coeffs. of ions in soln. from the Fuchs expansion of the grand potential in multicomponent systems is applied to the recently obtained expansion of the potential of average force in these systems." See Meeron, *J. Chem. Phys.* 27, 1238 (1957). "The resulting multiply infinite series are summed to give a series analogous to the original expansion, involving the DH potential of average force in a remarkably simple way. A similar expansion for the radial distribution function is presented. Explicit expressions for both quantities, exact through terms of first order in the ionic conc., are given. An expansion of the osmotic pressure, analogous to the virial expansion, is presented. The presence of the DH potential of average force in all these expansions is discussed, and the possibility of obtaining the potential of average force exact through terms of second order in the ionic charging parameters is indicated..." Cf. Friedman (1959) and Abe (1959); Montroll and Mayer, *J. Chem. Phys.* 9, 626 (1941); Kirkwood (1935); Kirkwood and Poirier (1954); Meeron, *Phys. Fluids* 1, 139 (1958); Meeron and Rodemich, *Phys. Fluids* 1, 246 (1958); Meeron, *J. Math. Phys.* 1, 192 (1960), *Progr. Theoret. Phys. (Kyoto)* 24, 588 (1960).

188. Meeron, E.: Topological methods in the cluster theory of ionic solutions. Report DL-92-0036; Boeing Scientific Laboratories Flight Sciences Lab. Report No. 18 (1959); to be published in the Archives of the Societa Italiana per il Progresso delle Scienze.

"The present paper is concerned mainly with the evaluation of all terms in the particle number density expansion of potentials of average force for which the Kirkwood superposition principle is valid.... departures from superposition will be shown to be given by a series of cluster integrals which give us departures of the actual system from ideality.... Although the present theory is generally applicable, we have discussed it principally in relation to ionic solutions. This is a logical outcome of the fact that, as we have seen, the DH screened potential is a special case of the chain potential defined in this discussion, and the terms obtained by Mayer are the first terms of a linear nodal expansion.... the cluster expansion outlined here is a special case of a still more general series, defined in terms of somewhat more advanced topological concepts. Thus one would be tempted to observe that further development of cluster theories, whether for ionic solutions or for more general systems, might be achieved through the use of methods of combinatory topology, in particular the theory of linear graphs."

Meyerott, R. E.: see Keller, G.

189. *Mikulin, G. I.: Electrostatic theory of concentrated electrolyte solutions. I. New method for the solution of the fundamental equation of the Debye-Hückel theory (in Ukrainian). Ukrain. Khim. Zhur. 21, 435-448 (1955).

"A new method was developed for solving the DH differential equation of the electrostatic theory of soln. This method makes simplification unnecessary and is free of the shortcomings of the Gronwall, La Mer, and Sandved (1928) theory. Special graphs and tables were devised for the calc. of the thermodynamic functions of soln.; thus the application of the DH theory was extended to solns. of electrolytes in nonaq. or mixed solvents with low dielectric constant and to solns. of electrolytes of high valency of ions or with a low value of 'ionic diameter.'" -- E. M. Elkin, CA 50, 6153 (1956).

190. Mikulin, G. I.: Effekt Dielektricheskovo Nasysheniya rastvoritelya v elektrostatischei teorii rastvorov. Zhur. Fiz. Khim. 33, 2419-2423 (1959).

Title: "Effect of dielectric saturation of the solvent in the electrostatic theory of solutions." Abstract: "An electrostatic theory of electrolytic solns. has been developed, accounting for the decrease in value of the dielectric constant of the solvent in an electrical field in the vicinity of an ion and the true significance of the correction in the DH theory has been evaluated..."

191. Milne, E. A.: Ionization in stellar atmospheres. Observatory 44, 261 (1921).

Remarks on Saha's formula.

192. Milne, E. A.: The dissociation formula according to the Fermi-Dirac statistics. Monthly Notices Roy. Astron. Soc. 90, 669-778 (1930).

Derives formulae for concentration and pressure of electrons in a partially degenerate gas, reducing to Saha equations when there is no degeneracy.

193. Milner, S. R.: The virial of a mixture of ions. Phil. Mag. (series 6) 23, 551-578 (1912).

This was the first attempt to calculate the pressure of a fully ionized gas (or the osmotic pressure of an electrolyte soln.) directly from statistical mechanics. The various difficulties connected with long- and short-range divergence are recognized and circumvented by an elaborate approximation method. The final results consist of a few numerical values for the virial, calcd. by extrapolating the values for various arrangements of small numbers of ions. The limiting laws for infinite dilution are not obtained, and the results hardly seem to justify the labor of calculation, though they do demonstrate that interionic forces may account for the observed variations of osmotic pressure with conc. See Nonhebel and Hartley (1926) for Milner's evaluation of the DH theory as compared with his own; see also Noyes (1924).

194. Milner, S. R.: The effect of interionic forces on the osmotic pressure of electrolytes. *Phil. Mag. (series 6)* 25, 742-751 (1913).
Application of the theory developed in previous paper. See Partington, J. *Chem. Soc.* 97, 1158 (1910) for a review of previous explanations of the variation of osmotic pressure with conc.
195. Milner, S. R.: The effect of interionic force in electrolytes. *Phil. Mag. (series 6)* 35, 214-220, 352-364 (1918).
Discusses whether electrical forces affect ionic mobilities and osmotic pressure.
196. Milner, S. R.: Note on the effect of interionic forces in electrolytes. *Trans. Faraday Soc.* 15, 148-151 (1919).
"The operation of electrical forces alone will cause a reduction in the osmotic pressure of the electrolyte below the theoretical values of $2RT_c$, which corresponds to complete dissociation with ionic pressures obeying the perfect gas law.... The exact determination depends on a knowledge of the law of interionic force. The inverse square law here naturally suggests itself, but its exact validity in solutions is open to question. It can, for example, only be approximately true that the effective dielectric constant of the few water molecules between neighbouring ions is, in these small scale actions, the same as that of water in mass. The water molecules may tend to form more or less polarised chains between neighbouring oppositely charged ions in a way which would modify appreciably the law of force..."
197. Möller, U.: Zur Theorie der Ionenlösungen. *Z. physik. Chem. (Leipzig)* 208, 220-234 (1958).
Die linearisierten Born-Greenschen Integralgleichungen für Mischungen werden näherungsweise durch Fouriertransformation gelöst. Für Systeme mit starren Kugeln, die im Zentrum Punktladungen tragen, werden die radialen Verteilungsfunktionen und die osmotischen Koeffizienten näherungsweise berechnet."
See Falkenhagen and Kelbg (1959) for summary of Möller's results.
198. Montroll, E. W., and Ward, J. C.: Quantum statistics of interacting particles; general theory and some remarks on properties of an electron gas. *Phys. Fluids* 1, 55-72 (1958).
"A systematic generalization of the Mayer cluster integral theory has been developed to deal with the quantum statistics of interacting particles. The grand p.f. appears in a natural way and the cluster integrals are integrals over propagators which are derived from the Green's function solution of the Bloch eqn. (which follows from the Schrödinger eqn. by replacing i/\hbar by $\beta = 1/kT$). Every cluster integral can be represented by a hybrid of a Mayer graph and a Feynman diagram in (β, r) space. The generalization of classical ring cluster integrals has been analyzed. It is shown that in the case of the electron gas the classical limit of the contribution of these integrals to the grand p.f. yields the DH theory [Cf. Mayer

(1950), Zubarev (1954)] while the low temperature limit leads to the Gell-Mann--Brueckner (1957) eqn. for the correlation energy of the ground state. A prescription is given for the construction of the cluster integral associated with any given diagram."

199. Montroll, E. W., and Ward, J. C.: Quantum statistics of interacting particles. *Nuovo cimento Suppl.* 9, 235 (1958).

Summary of the above paper.

200. Montroll, E. W.: Topics on statistical mechanics of interacting particles. In La Théorie des gaz neutres et ionisés: Le problème des n corps à Temperature non nulle. (Edited by C. DeWitt and J. F. Detoeuf.) P. 1-148. Hermann, Paris (1960).

Lectures on Gibbs ensembles and p.f.'s cluster integral theory (including the Montroll-Ward theory), etc.

Montroll, E. W.: see Berlin, T. H.

201. Morita, T.: Theory of Classical Fluids: Hyper-Netted Chain Approximation, I. *Progr. Theoret. Phys. (Kyoto)* 20, 920-938 (1958).

Develops the "watermelon approximation" based on a suggestion of Abe, generalizing the ring approximation of Montroll and Mayer (*J. Chem. Phys.* 9, 626 (1941)) in cluster integral theory. The results for particles interacting with Coulomb forces are compared with those of Mayer (1950), Zubarev (1954), and Meeron (1957); see also Haga (1953) and Yukhnovskii (1958). Meeron (*ibid.* 24, 588 (1960)) discusses the equivalence of his method and that of Morita's.

202. Morita, T.: Equation of state of high temperature plasma. *Progr. Theoret. Phys. (Kyoto)* 22, 757-774 (1959).

The eqn. of state of a high temperature plasma is studied using quantum mechanics; "...it is shown that the DH approx. surely applies to the plasmas of low density of the order 10^{15} to 10^{17} or so at high temperatures where $\lambda_e \lesssim a_0/Z$, where Z is the charge of a nucleus, λ_e the de Broglie wave length of an electron and a_0 the Bohr radius. This result is confirmed by reducing the problem to that of a suitable classical gas and confirming that the contribution of the watermelon terms -- which is considered as the leading correction to the DH approx. -- is negligible compared with that of the ring terms considered in the DH approx." Cf. Abe (1959).

203. Müller, H.: Die Aktivitätskoeffizienten kleiner Ionen. *Physik. Z.* 28, 324-333 (1927); 29, 78-82 (1928).

Discussion of validity of DH theory; calc. of activity coeffs. taking account of ionic radius. See Onsager (1933).

204. Munster, A.: Statistische Thermodynamik. Springer-Verlag, Berlin (1956).

Ch. XXI: Lösungen starker Elektrolyte. Discussion of DH theory, Kirkwood-Poirier paper (1954).

Myers, H.: see Benson, S. W.

205. Natanson, G. L.: Fluctuations of charged density in electrolytes.

Compt. rend. acad. sci. U.R.S.S. 53, 115-118 (1946).

See CA 41, 2649 (1947); Leontovich (1946).

206. *Natanson, G. L.: Simmetrichnaia elektrizatsiia kapel' pri mekhanicheskoi raspylenii zhidkosti. Zhur. Fiz. Khim. 25, 779-790 (1951).

Cited by Falkenhagen and Kelbg (1959); see also Fisher (1952).

207. Nernst, W.: Zur Theorie der Elektrolytischen Dissoziation. Z. Elektrochem. 33, 428-431 (1927).

"N. would combine the positive heat of diln. obtained from the theory of Debye with the heat of dissocn. in diln. of an electrolytic soln. in order to get the true heat of diln. The former alone is often contradictory to facts since in dil. solns. the heat of diln. may be negative. Very accurate data confirm his suggestion." -- CA 22, 342 (1928).

Neumann, K. K.: see Kroepelin, H.

208. Nonhebel, G., and Hartley, H.: The Milner and Debye theories of strong electrolytes. Phil. Mag. (series 7) 2, 586-587 (1926).

They quote a letter from Milner: "Since I have read Debye's calculation critically I think that his method of calculation of the effects of interionic force is greatly superior to mine. All the laborious summations and approximations contained in my calculation of 1912 are done away with, without any sacrifice of accuracy, by what seems to me a stroke of genius -- namely, his observation that the average potential of all the ions in a sphere containing a positive ion at the centre must satisfy Poisson's equation. Since the two calculations are based on the same assumptions and mine contains admitted approximations, I am inclined to believe that the numerical differences between them are to a large extent attributable to these. At any rate, I think this is the case with regard to the $\sqrt{\pi}/2$ ratio, by which the limiting values of the internal energy at $h = 0$ differ.... It was clear to me that the coefficient was only an approximation even in the limit."

Nonhebel, G.: see also Pike, S. R.

209. Noyes, A. A., and Wilson, H. A.: The thermal ionization of gaseous elements at high temperatures: A confirmation of the Saha theory.

Astrophys. J. 57, 20 (1923).

210. Noyes, A. A.: The inter-ionic attraction theory of ionized solutes.

I. Critical presentation of the theory. J. Am. Chem. Soc. 46, 1080-1097 (1924).

"The treatment of Milner (1912) involved mathematical considerations so difficult as to make it scarcely available to chemists or physicists with ordinary mathematical training. The more recent derivation of Debye and Hückel, on the other hand, is based on a few fundamental physical principles whose application presents no serious mathematical difficulties." Comparison of the two theories.

211. Nozieres, P., and Pines, D.: Correlation energy of a free electron gas. *Phys. Rev.* 111, 442-454 (1958).
"The limits of validity of the correlation-energy calculations in the regions of high density, low density, and actual metallic electron densities are discussed."
212. Oka, S.: Van der Waals forces and the Debye-Hückel theory of strong electrolytes. *Proc. Phys.-Math. Soc. Japan* 20, 11-14 (1938).
"Van der Waals forces as well as the ordinary Coulomb forces between ions are considered in the determination of the potential due to the ionic atmosphere. Under certain assumptions it is shown that the van der Waals forces can be neglected in the case of sufficiently dilute solns. Thus the thermodynamic limiting laws of strong electrolytes in the theory of Debye and Hückel are justified."
213. Ono, S.: Statistical thermodynamics of solutions of electrolytes and non-electrolytes. *Progr. Theoret. Phys. (Kyoto)* 6, 447-457 (1951).
"The generalized Born-Green integral equations for solutions of electrolytes and non-electrolytes are derived according to the method previously shown [*ibid.* 5, 822 (1950)]. The assumption of superposition for the potentials for average force of solute molecules or ions is employed. . . . The integral equations may be used, if the potentials of average force at infinite dilution are known, to compute the deviation from perfect solution behaviour."
214. Onsager, L.: Zur Theorie der Elektrolyte. II. *Physik. Z.* 28, 277-298 (1927).
Misc. extensions and applications of the DH theory.
215. Onsager, L.: Activity coefficients and mass-action law in electrolytes. *J. Phys. Chem.* 32, 1461-1466 (1928).
Shows that Soper's formula for the activity coeff. in an electrolyte soln. (Soper 1927, 1928), which is $2/3$ of that found in the DH theory, is wrong.
216. Onsager, L.: Theories of concentrated electrolytes. *Chem. Revs.* 13, 73-89 (1933).
Discussion of potential of average force and calc. of Coulomb energy. Müller (1927) obtained a result different from that of Gronwall, La Mer, and Sandved (1928), and he then accepted their criticism and computed his own "error" (Müller 1928). "In view of the general results obtained in section I, we must take a different view of Müller's 'error,' namely that either charging process is legitimate, but the PB eqn. is not entirely self-consistent [cf. Fowler (1927), Onsager (1927)] Fowler's 'fluctuation-terms' are of the same order of magnitude as the maximum of the main terms in [the PB eqn.] . . . , but they are nearly cancelled . . . by a supplementary term, which he omitted through an oversight. . . ." The effect of short range forces is also discussed.

217. Pannekoek, A.: Die Ionisation in den Atmosphären der Himmelskörper. Handbuch der Astrophysik 3:1, Kap. 3, p. 256-350 (1930).
Theory of ionization equilibrium.
Pauling, L.: see Debye, P.
Pedlosky, J.: see Covert, E. E.
Peierls, R.: see Fuchs, K.
Peletninskii, S. V.: see Akhiezer, I. A.
218. Pike, S. R., and Nonhebel, G.: Note on the theory of interionic attraction in strong electrolytes. *Phil. Mag. (series 6)* 50, 723-728 (1925).
The formulae of Milner (1912) and of Debye and Hückel (1923), for the electrostatic energy, disagree by a factor of $\sqrt{\pi/2}$ in the limit of extreme dilution. The possibility of deciding between the two theories on the basis of experimental evidence is discussed, and it is concluded that the evidence is not yet sufficient to do this.
219. Pines, D.: A collective description of electron interactions: IV. Electron interaction in metals. *Phys. Rev.* 92, 626-636 (1953).
"The ground state energy of the free electron gas is determined, and an estimate of the correlation energy is obtained, with results in good agreement with those of Wigner (1934)." Pines also comments on the work of Bardeen (1936) and Wohlfarth (1950) who found that the inclusion of the exchange energy makes the specific heat vary as $T/\ln T$ in contradiction with experimental results.
220. Pines, D.: Electron interaction in metals. Solid State Physics: Advances in Research and Applications, Vol. I, p. 367-450. Academic Press, New York (1955).
Review article. Collective description of electron interactions, correlation energy of the free electron gas, plasma oscillations.
Pines, D.: see also Nozières, P.
Pleshonov, A. S.: see Predvoditelev, A. S.
221. Plock, R. J.: I. Non-Newtonian viscoelastic properties of rod-like molecules in solution. II. The Debye-Hückel, Fermi-Thomas theory of plasmas and liquid metals. Ph.D. Dissertation, Yale (1957).
222. Poirier, J. C.: Thermodynamic functions from Mayer's theory of ionic solutions. I. Equations for thermodynamic functions. *J. Chem. Phys.* 21, 965-972 (1953).
"From the partial molal free energy expression defining Mayer's activity coeff., there are derived in this paper expressions for five usually measured thermodynamic functions..."
223. Poirier, J. C.: Thermodynamic functions from Mayer's theory of ionic solutions. II. The stoichiometric mean ionic molar activity coefficient. *J. Chem. Phys.* 21, 972-985 (1953).

"The formula for the s.m.i.m.a.c. of strong electrolytes in aqueous soln. at 25° C. arising from Mayer's theory is compared with published experimental data..."

224. Poirier, J. C., and DeLap, J. H.: On the theory of ion pairs in solutions. *J. Chem. Phys.* 35, 213 (1961).

Calculation of activity coefficients following method of Fuoss (1934).

Poirier, J. C.: see Kirkwood, J. G.

225. Prager, S.: Equilibrium statistical mechanics of the one-dimensional plasma. *Bull. Am. Phys. Soc.* 6, 246 (1961) [Abstract].

226. Predvoditelev, A. S., Stupochenko, E. V., Samuilov, E. V., Stakhanov, I. P., Pleshanov, A. S., and Rozhdestvenskii, I. B.: Tablitsy Termodinamicheskikh Funktsii Vozdukh (dlya temperatur ot 6000° do 12000° K i davlenii ot 0.001 do 1000 atmosfer). Izd. Akad. Nauk S.S.S.R., Moscow (1957). Tables of Thermodynamic Functions of Air for the Temperature range 6000-12000° K and pressure range 0.001-1000 atm. Infosearch, London (1958).

"The thermodynamic functions and the composition of air were calcd. by the methods of statistical physics, taking into account dissociation of N₂ and O₂, formation of NO, and single charge ionisation of N₂, O₂, NO, N, O, and Ar, but without taking into account interactions between gas particles..."

See also Stupochenko et al. (1961).

227. Raizer, Y. P.: A simple method of calculating the degree of ionization and thermodynamic functions of a multiply ionized gas. *Zhur. Eksptl. i Teoret. Fiz.* 36, 1583-1585 (1959); *Soviet Phys. JETP* 36, 1124-1125 (1959).

The method is based on the use of approximations which convert the Saha and thermodynamic equations into differential form. Some results are quoted for the case of air.

228. Raymond, J. L.: Thermodynamic properties of the atmosphere of Venus. RAND Corp. Report RM-2292 (1958).

"This study assumes a 100% carbon dioxide atmosphere in the temp. range of 1,000° K to 24,000° K and pressure range of 10⁻⁴ to 10²..."

Roberts, J. E.: see Harris, G. M.

229. Robinson, R. A., and Stokes, R. H.: Electrolyte Solutions: The Measurement and Interpretation of Conductance, Chemical Potential and Diffusion in Solutions of Simple Electrolytes. Academic Press, New York (1955); second edition 1959.

Discussion of DH theory and papers of Eigen and Wicke (1951, 1952, 1953), p. 74-86.

230. Rosseland, S.: Electrical state of a star. Monthly Notices Roy. Astron. Soc. 84, 720-728 (1924).

Calc. of the electrical pressure by DH theory. He remarks that "A rigorous treatment would also have to take account of the fact that in the close vicinity of an ion the motion of an electron will be restricted by quantum conditions." Also: "a rigorous theory would have to apply Boltzmann's principle ab initio to a general assembly of particles in the manner attempted by Milner (1912)."

231. Rossi, R. A., and Feduchak, J.: Kinetic study of rocket exhaust gases. Progress Report No. 1 (1960).

"Ionization occurring in high-temperature gases is investigated through the use of the Saha relationship. For a model gas having an ionization potential of 13 ev, the ionization fraction and number of free electrons per cm^3 are presented. . ."—Nuclear Sci. Abstr. 15, 835 (1961).

232. Rother, H.: Zur Berechnung der effektiven Ionisierungsspannung in Plasmen. Ann. Physik (series 7) 2, 326-328 (1958).

"Derives an expression for the lowering of the ionization voltage resulting from impact ionization by electrons. The relevant quantum number as a function of particle density agrees satisfactorily with experimental values." -- C. G. Morgan, PA 62, 329 (1959). Rother's results are discussed by Duclos (1960, p. 49).

233. Rouse, C. A.: Ionization equilibrium equation of state. UCRL 5695 (1959-1961). Astrophys. J. (in press).

"A complete solution to Saha's equation has been obtained for a monatomic gas. The method of solution involves iteration with respect to the electron pressure or electron conc. and can be applied to the simultaneous calcs. of any number of ions. Some results are given in tabular form." Ref. 350.

Rozhdestvenskii, I. B.: see Predvoditelev, A. S.

234. Russell, H. N.: The theory of ionization and the sun-spot spectrum. Astrophys. J. 55, 119 (1922).

Saha's theory extended to mixtures.

235. Russell, H. N.: Mean ionization in stellar atmospheres. Astrophys. J. 75, 337 (1932).

Mean ionization calculated for a gas of the composition found by the author for the solar atmosphere, over a range of temperature from 1700° to $25,000^\circ$ K, and of electron pressure from 10^3 to 10^{-20} atm. Saha's formula is used with a modification suggested by Pannekoek (1930) to take account of radiation effects. Partition functions based on several excited states are used.

236. Rysselberghe, P. van: The limiting laws of the interionic attraction theory of strong electrolytes. J. Chem. Phys. 1, 205-209 (1933).

"...it is possible to obtain directly the general form of the limiting laws of strong electrolytes from the combined use of the Gibbs-Helmholtz formula and the virial theorem of Clausius. It is then shown that the DH and the Kramers (1926) limiting laws are particular forms of these general laws."

Criticized by Halpern (1934).

237. Rysselberghe, P. van: Theorems concerning the activity coefficients and osmotic coefficients of strong and weak electrolytes. *J. Phys. Chem.* 39, 403-414 (1935).
Thermodynamic discussion of necessary relations between various sets of activity coefficients.
238. Rysselberghe, P. van, and Eisenberg, S.: Activity coefficients in concentrated aqueous solutions of strong electrolytes described by a formula containing the mean ionic diameter as single parameter. I. Theory and application to the alkali chlorides, bromides, and iodides. *J. Am. Chem. Soc.* 61, 3030-3037 (1939).
Adds van der Waals "covolume" terms to the DH theory using the method of Ursell, *Proc. Cambridge Phil. Soc.* 23, 685 (1927). See next ref. for correction.
239. Rysselberghe, P. van, and Eisenberg, S.: Activity coefficients in concentrated aqueous solutions of strong electrolytes described by a formula containing the mean ionic diameter as single parameter. II. Corrected formulation. *J. Am. Chem. Soc.* 62, 451-452 (1940).
The formula given in part I is "a purely empirical contribution" with "no theoretical basis" and "we are very much indebted to Dr. H. C. Eckstrom for calling our attention to the fact that" Ursell's theory was applied incorrectly. Other possible corrections which might in future be considered -- variation of dielectric constant with conc., etc. -- are mentioned.
240. Saha, M. N.: Ionization in the solar chromosphere. *Phil. Mag.* (series 6) 40, 472-488 (1920).
Nernst's theorem of the "reaction-isobar" is used to discuss ionization-equilibrium in a star. See also Eggert (1919).
241. Sakakura, A. Y.: The connected diagram expansion of the grand partition function and the statistical mechanics of the electron gas. Thesis, University of Colorado, 1960. TID-11028.
"The connected diagram expansion of the grand partition function, generalized to include many-component systems with external fields, was obtained by means of second quantization and Wick's theorem. This was accomplished by expanding the iterative solution of the Bloch eqn. into a sum of normal products and by directly evaluating the traces of these normal products.... For the case of pair interactions alone, the diagrams were simplified by the separation into

the irreducible diagrams and the polarization parts in analogy with ground-state theories. The integral equation satisfied by the polarization parts was derived, and the rules for computing the eigenvalues of this integral eqn. were given. It was shown that the lowest order eigenvalues yielded the Montroll-Ward ring contributions. With the inclusion of the first- and second-order irreducible diagrams, the ground-state energy of the electron gas was derived to second order. . . . The ring contribution to the grand p.f. containing all possible combinations of the first-order exchange interactions is obtained by including the eigenvalues corresponding to kernels with one internal line. From this the eqn. of state and the internal energy of the electron gas in the near classical limit were extended to include terms of order $\Lambda \gamma$, γ^4 , and $\Lambda \gamma^2$. A method of absorbing all passive particle interaction into a contraction symbol was given, and a simple ladder diagram was summed."

Salpeter, E. E.: see Bowers, D. L

Samuilov, E. V.: see Predvoditelev, A. S.

Sandved, K.: see Gronwall, T. H.

242. Scatchard, G.: The Milner and Debye theories of strong electrolytes. *Phil. Mag. (series 7)* 2, 577-586 (1926).

Milner's numerical results are not to be taken as strict consequences of his theory because of the complicated method of calc. and extrapolation which he used. The DH theory on the other hand "is so direct in its development that the approx. may be improved at any time by including more terms in the series used to approximate the Boltzmann equation."

243. Scatchard, G.: The coming of age of the interionic attraction theory. *Chem. Revs.* 13, 7-27 (1933).

"The present occasion is then a very fitting one to stop and consider just what this adolescent theory is, just what it has already accomplished, what may be expected of it in the future, and what our attitude toward it is to be." Nonmathematical review of the contributions of Arrhenius, van Laar, Debye and Hückel, Bjerrum, Müller, Gronwall and La Mer, etc.

244. Scatchard, G., and Epstein, L. F.: The calculation of the thermodynamic properties and the association of electrolytic solutions. *Chem. Revs.* 30, 211-226 (1942).

"A convenient system of representing thermodynamic data for salt solutions is described, in which: (1) the Debye κ is taken proportional to the ionic strength per unit volume of solvent; (2) the Debye limiting law is expressed as an analytical function of the temperature; (3) the mean collision diameter a is taken inversely proportional to μ at constant composition; (4) the function

$$z = 1 + \kappa a - (1 + \kappa a)^{-1} - 2 \ln \frac{1 + \kappa a}{(\kappa a)^3}$$

is presented in a table of z vs. $g = \kappa a / (1 + \kappa a)$; (5) the deviations from the DH approx. are treated as an apparent association, with

the constant determined to agree with analytical methods for the term proportional to the ionic strength; (6) the calc. of association, either electrostatic or chemical, is made on the assumption that short-range forces are independent of the association; (7) deviations from these relations are expressed graphically as deviations from a power series in the concs...."

245. Scatchard, G.: [Discussion remark after paper by Eigen and Wicke (1954)] *J. Phys. Chem.* 58, 713-714 (1954).
 Criticism of Eigen-Wicke theory. "Although the work of displacing the charged medium should be included in the electrostatic work, the statistics used for the case of unequal volumes seem seriously at fault in that the electrostatic interaction of two ions of the atmosphere is calcd. as depending only on their distance from the central ion and not on their distance from each other."
 See Eigen's reply, *ibid.* p. 714.
246. Scatchard, G.: The interpretation of activity and osmotic coefficients. Chapter 2 in The Structure of Electrolyte Solutions. John Wiley & Sons, New York (1959).
 Discusses various proposed improvements and extensions of the DH theory.
247. Schatzman, E.: L'Entropie d'un mélange de gaz en équilibre d'ionisation. *Bull. acad. roy. Belg. (cl. Sc.)* 34, 748-753 (1948).
 "Formulae are given for the calc. of entropy when atoms have several degrees of ionization. Calcs. are given for O." -- R. A. Newing, *PA* 52, 577 (1949).
248. Schlögl, R.: Erwiderung auf die vorhergehende Arbeit von E. Hückel und G. Krafft, "Untersuchungen über den Einfluss der Ionengrößen auf das thermodynamische Verhalten von Elektrolytlösungen." *Z. physik. Chem. (Frankfurt)* 3, 176-177 (1955).
 Comments on paper by Hückel and Krafft (1955).
249. Selivanov, V. V., and Shlyapintokh, I. Y.: Thermodynamic properties of air on thermal ionisation and the shock wave. AD 225148, translated from *Zhur. Fiz. Khim.* 32, 670-678 (1958).
 Calc. for temperature range 2×10^4 to 5×10^5 K, densities from $10\rho_0$ to $10^{-3}\rho_0$ where ρ_0 is the initial density at 0° and 1 atm pressure. See *CA* 52, 17860 (1958).
250. *Semenchenko, V. K.: Fizicheskaya Teoriya Rastvorov. Gostekhizdat, Moscow (1941).
251. Senter, G., et al.: The present position of the theory of ionisation. A general discussion. *Trans. Faraday Soc.* 15, 3-178 (1919).
 Collection of papers on theory and experiment; many comments about the past history and present status of the subject.

252. *Shakhparanov, M. I.: Nekotorye Voprosy Fizicheskoi Teorii Rastvorov.
Dissertation, Moscow State University (1952).
253. Shakhparanov, M. I.: Vvedenie v Molekulyarnuyu Teoriyu Rastvorov.
Gosudarst. Izd. Tekh.-Teor. Lit., Moscow (1956).
Ch. X: "Statistical theory of solutions of electrolytes" -- DH theory, Bogolyubov's derivation of the binary distribution function (1946), theory of conc. solns., work of Semenchenko and Bjerrum, empirical formulae for conc. solns., application of Bogolyubov method by Yukhnovskii and Glauber, Mayer's theory (1950); review of author's own work on neutral molecules in ionic solvents; investigations of structure in ionic solutions. References to Russian work.
Shlyapintokh, I. Y.: see Selivanov, V. V.
254. Soper, F. G.: The velocity of interaction of ions. *J. Phys. Chem.* 31,
1790-1797 (1927).
See Onsager (1928).
255. Soper, F. G.: Equilibrium in electrolyte solutions. *J. Phys. Chem.*
32, 67-71 (1928).
See Onsager (1928).
Stakhanov, I. P.: see Predvoditelev, A. S.
Stokes, R. H.: see Robinson, R. A.
256. Strel'tsova, E. A.: K voprosu o funktsiyakh raspredeleniya dlya sistem
s Kulonovskim vzaimodeistviem. *Zhur. Eksptl. i Teoret. Fiz.* 26,
173-178 (1954).
The distribution function of a system of charged particles is found by solving Bogolyubov's equations (1946). The first-order equation gives the DH result, as already shown by Bogolyubov; the next correction to the free energy appears to contain a logarithmically divergent term. See also *Doklady Akad. Nauk S.S.S.R.* 116, 820 (1957).
257. Stupochenko, E. V., et al.: Thermodynamic properties of air between
1000° and 12,000° K and 0.001 and 1000 atmospheres. P. 1-40 in
Physical Gas Dynamics, edited by A. S. Predvoditelev, translated by
R. C. Murray and D. R. H. Phillips; Pergamon Press, New York
(1961).
Description of calculations published by Predvoditelev et al. (1957).
Stupochenko, E. V.: see Predvoditelev, A. S.
258. Suhl, H., and Werthamer, N. R.: Higher random-phase approximations
in the many-body problem. *Phys. Rev.* 122, 359-366 (1961).
"The usual random-phase approx. [Bohm and Pines, *Phys. Rev.*
92, 626 (1953)] combined with an equations-of-motion technique for
the many-electron problem is extended, yielding many of the known

results of series summation methods [Dubois 1959, Gell-Mann 1957] in a straight-forward manner. The method should apply to other types of many-body problems as well."

Sumida, D. Y.: see Hilsenrath, J.

259. Theimer, O.: Über die effektive Ionisierungsspannung eines Atoms im Inneren des Plasmas. Z. Naturforsch. 12a, 518-519 (1957).

"The ionization potential is reduced in the presence of free ionization, as in a plasma, and this reduced potential is discussed briefly in terms of the DH theory and the more recent work of Ecker and Weizel (1956, 1957, 1958)." -- J. D. Craggs, PA 62, 678 (1959).

260. Theimer, O.: Über die Wechselwirkungsenergie der Ladungsträger in einem Plasma. Z. Naturforsch. 13a, 568-569 (1958).

"... ist es überraschend, dass Ecker und Weizel (1956, 1957) die Wechselwirkung der Ladungsträger in einem Plasma nach einer Methode berechnen, die sowohl in ihren Resultaten als auch in ihren physikalischen Grundlagen mit der DH Theorie unverträglich ist..."
See also PA 62, 443 (1959).

Thompson, P. T.: see Frank, H. S.

261. Tiablikov, S. V., and Tolmachev, V. V.: K klassicheskoi teorii silnykh elektrolitov. Nauchnye Doklady Vysshei Shkoly, Fiziko-matematicheskie Nauki, No. 1, 101-109 (1958).

"The difficulties of the statistical free energy calc. for electrolytes are discussed critically, esp. the consideration of ion interactions, which have been superseded by Debye's work. This theory [DH] is compared with results obtained from Bjerrum's theory; doubt is expressed as to the validity of results derived from Bjerrum's theory." -- A. Kremheller, CA 53, 7730 (1959). See Vedenov (1959).

262. Timan, B. L.: The influence of the interaction between particles on the ionization equilibrium in thermally ionized gas. AEC-tr-2279; translated from Zhur. Eksptl. i Teoret. Fiz. 25, 733-737 (1953). Also Translation RJ-441, Assoc. Tech. Serv., East Orange, N. J.

"The ionization equil. in a gas at high temperatures and pressures is investigated theoretically. Taking into account interaction between the gas particles leads to the displacement of the ionization equil. in the direction of increase in the number of ionized particles with increasing pressure. A comparison with exptl. data is made."

263. Timan, B. L.: Heat capacity of gases at high temperatures. Zhur. Eksptl. i Teoret. Fiz. 27, 262-264 (1954); UCRL Trans. 672 (L).

The heat capacity at constant volume is calculated for a monatomic gas capable of single ionization only. Effects of interaction are not included.

264. Timan, B. L.: Vliyanie vzaimodeistviya ionov na ikh ravnovesnye kontsentratsii v sluchae mnogokratnoi termicheskoi ionizatsii gaza.

Zhur. Eksptl. i Teoret. Fiz. 27, 708-711 (1954). UCRL Trans. 674 (L).

"By the application of the DH theory it is shown that the interaction between the ions has a considerable effect on the equilibrium under conditions to be found in stars." -- J. M. Hough, PA 58, 805 (1955).

265. Tolmachev, V. V.: K klassicheskoi teorii silnykh elektrolitov. Doklady Akad. Nauk S.S.S.R. 119, 314-317 (1958).

"The statistical basis of the DH and Bjerrum corrections to the change in the free energy due to ionic attraction in strong electrolytes is discussed." -- J. R. Leach, CA 53, 3847 (1959). Criticized by Vedenov (1959).

Tolmachev, V. V.: see also Tiablikov, S. V.

266. Trulio, J. G., and Brush, S. G.: Correction to the Debye-Hückel theory. Phys. Rev. 121, 940 (1961).

Abe's S_2 integral (see Abe 1959) is evaluated numerically for a one-component classical electron gas and the results compared with those given by Bowers and Salpeter (1960).

267. Trulio, J. G., and Brush, S. G.: Evaluation of some integrals arising in the theory of ionized gases. I. UCRL 6450 (Pt. I) (1961).

The S_2 integral defined by Abe (1959), which also appears in the theories of Friedman (1959) and Meeron (1957, 1958), is evaluated numerically for a modified Coulomb potential similar to that used by Glauber (1951). The results are relevant to the free energy of a system of positive and negative charges.

Trulio, J. G.: see Harris, G. M.

268. Uhlenbeck, G. E.: Successive approximation methods in classical statistical mechanics. Physica 26, S17-27 (1960).

Review of work on graph theory applied to virial expansions, and brief remarks on the diagram expansion for the equation of state of a plasma.

269. Unsöld, A.: Physik der Sternatmosphären mit besonderer Berücksichtigung der Sonne. J. Springer, Berlin (1938).

Chapter IV deals with thermal ionization and gives useful tables for calculations with the Saha formula.

270. Unsöld, A.: Zur Berechnung der Zustandsummen für Atome und Ionen in einem Teilweise Ionisierten Gas. Z. Astrophys. 24, 355-362 (1948).

"Im Anschluss an eine frühere Arbeit von M. Planck [Ann. Physik 75, 673 (1924)] wird ein handliches Verfahren zur Berechnung der Zustandsumme von Atomen und Ionen in teilweise ionisierten Gasen entwickelt. . . . Das Verhältnis zwischen den Darstellungen von Planck und uns einerseits, Urey und Fermi andererseits wird klargestellt. . . ."

See Fowler (1929) for summary of theories of Planck, Urey and Fermi.

Van Rysselberghe, P.: see Rysselberghe, P. van.

271. Vedenov, A. A.: Thermodynamic properties of degenerate plasma. Zhur. Eksptl. i Teoret. Fiz. 36, 641-642 (1959); Soviet Phys. JETP 9, 446-447 (1959).
 "Using the diagram technique [Matsubara, Progr. Theoret. Phys. (Kyoto) 14, 351 (1955)] for statistical Green's functions in quantum statistical mechanics, we have calcd. the interaction correction for the thermodynamic potential of a completely ionized degenerate plasma for the case in which the electron plasma is a Fermi gas while the nuclei form a Boltzmann gas."
 The result given by Landau and Lifshitz (1958) is wrong because it "does not take account of the exchange energy of the electrons and the self-consistent term has been computed incorrectly."
272. Vedenov, A. A.: A new method in classical statistical physics. Doklady Akad. Nauk S.S.S.R. 125, 757-760 (1959); Soviet Phys. Doklady 4, 364-368 (1959).
 Method of evaluating the p.f. by expanding in powers of inverse temperature and Fourier transformation of the two-particle correlation function. Applied to the calc. of the 2nd virial coeff.; also gives DH formulae for a completely ionized gas (details in next ref.).
273. Vedenov, A. A.: Free energy of strong electrolytes. Zhur. Eksptl. i Teoret. Fiz. 36, 942-943 (1959); Soviet Phys. JETP 9, 665-666 (1959).
 The method used in the above ref. for calculating the pair correlation function is here applied to calc. the free energy of a strong electrolyte soln. The result of Tolmachev (1958) and Tiablikov and Tolmachev (1958) is said to be incorrect.
274. Vedenov, A. A., and Larkin, A. I.: Equation of state of a plasma. Zhur. Eksptl. i Teoret. Fiz. 36, 1133-1142 (1959); Soviet Phys. JETP 9, 806-811 (1959).
 "The free energy F of a completely ionized gas is given in terms of the density n:

$$F = F_{\text{ideal}} + An^{3/2} + Bn^2 \ln n + Cn^2$$
 The term $An^{3/2}$ is identical with the familiar DH term. Expressions for B and C have been obtained. A diagram technique has been used to carry out the calcs." The work of Glauber and Yukhnovskii (1952) is criticized.
 This paper is reviewed by Duclos (1960, p. 95-97) who says "it seems highly unlikely that the Vedenov-Larkin equation of state is correct."
275. *Veis, Š.: Rendering Saha's equation more accurate for the case when the interaction of the ions is expressed by "distant" forces. Českoslov. časopis pro fysiku A10, 394-403 (1960). In Czech, with English abstract in Czechoslov. J. Phys. B11, 1295 (1961); also Nuclear Sci. Abstr. 15, 1322-1323 (1961).

"The equilibrium concs. of ions of thermically ionized gases are investigated. If the interaction of the particles of the ionized gas is expressed in the form of "distant" forces we obtain Saha's equation for the equilibrium concs. of ions. The Saha equation derived here represents the influence of the interaction of the ions and is more general than the Saha equation derived by B. L. Timan, who expressed the interaction of the ions as a purely Coulomb equation."

276. Veldhuizen, H. van: De Theorie van Debije en Huckel en haar experimentele Toetsing. I, II. Chem. Weekblad 27, 486-492, 681-685 (1930).
- "A discussion of the numerous theoretical and experimental investigations designed to verify the theory of Debye and Hückel concerning electrolytes." -- E. Schotte, CA 25, 3903 (1931).
277. Villars, D. S.: Equation of state of gaseous metallic plasmas. Bull. Am. Phys. Soc. (series II) 6, 370 (1961).
- "An attempt has been made to implement a theory of H. S. Green which calculates the equation of state from correlation functions."
- Ward, J. C.: see Montroll, E. W.
278. Watson, K. M.: Cooperative interactions in a plasma. Physica 26, S188-196 (1960).
- Brief remarks on the equation of state of a high-temperature, low-density plasma.
- Wegstein, J. H.: see Hilsenrath, J.
- Weizel, W.: see Ecker, G.
- Werthamer, N. R.: see Suhl, H.
279. Wheeler, T. S.: Zur allgemeinen Theorie der Lösungen starker Elektrolyte. Physik. Z. 32, 674-680 (1931).
- "The expression for the elec. work of diln. of a dil. soln. of a strong electrolyte, whose ions attract or repel according to a law of force of which Coulomb's law is a special case, is obtained as the sum of a series of terms. Each term is a potential energy, which depends on the assumed law of force, multiplied by a power of the ratio of this energy to a kinetic energy. The virial of Clausius can be derived from the expression thus developed. The general forms of the thermodynamic functions which can be obtained from the work function are given. The relations of the general expression to the special formulations of Ghosh, Milner, and Debye are indicated." -- E. R. Smith, CA 26, 19 (1932).
280. Wheeler, T. S.: The theory of equations of state. Phil. Mag. (series 7) 13, 604-615 (1932).
- "A general expression for the work of dilution of a system of charged particles in thermal equilibrium is deduced by thermodynamic and dimensional considerations. The equation is applied to solns. of strong electrolytes and compared with the DH expression; potentials

of crystal lattices are calcd.; 2nd virial coeff. of A is calcd.; it is shown that in the van der Waals equation the cohesive power varies as the inverse 4th power of the distance. For the case of strong electrolytes with ions of finite size, calc. for K_2SO_4 gives the particle size larger than the DH theory but of the right order." -- A. Fleischer, CA 26, 3416 (1932).

281. White, W. B., and Krieger, F. J.: The composition and thermodynamic properties of air at temperatures from 500° to 8000°K and pressures from 0.00001 to 100 atmospheres. RAND Report R-149 (1949).
282. Wicke, E., and Eigen, M.: Über den Einfluss des Raumbedarfs von Ionen in wässriger Lösung auf ihre Verteilung im elektrischen Feld und ihre Aktivitätskoeffizient. Z. Elektrochem. 56, 551-561 (1952).
 "The space requirements of ions, detd. essentially by the amt. of hydration, must be considered in their distr. function... 2 limiting idealized cases are presented: (a) cations and anions as equally large rigid spheres and (b) different space requirements of the 2 kinds of ions and complete interpenetrability of oppositely charged ions..." -- CA 47, 2020. For numerical calcs. and graphs see Naturwissenschaften 39, 545 (1952).
283. Wicke, E., and Eigen, M.: Raumbedarf und Aktivitätskoeffizienten starker Elektrolyte in wässriger Lösung. Z. Naturforsch. 8a, 161-167 (1953).
 "Discusses the analogy between the variation of the coeff. of activity with conc. and the behaviour of real gases. An expression is derived for the distribution of strongly hydrated ions in the ionic cloud, which takes into account the effect of the mutual spatial displacement. The distribution function is based on the assumption of partial penetration of hydrate shells of the ions of opposite rings. If this function is substituted for the simple Boltzmann distribution in the theory of Debye and Hückel, it becomes possible to portray accurately the variation of the coeff. of activity with conc." -- F. Lachman, PA 56, 608 (1953).
284. Wicke, E., and Eigen, M.: Thermodynamische Eigenschaften konzentrierter wässriger Elektrolytlösungen. Z. Elektrochem. 57, 319-330 (1953).
 "In considering the thermodynamic properties of electrolyte solns. in the conc. range 0.1-2 M, two modifications of the DH theory are introduced: (1) the hydration spheres of similarly charged ions do not interpenetrate; (2) oppositely charged ions form ion pairs, setting up a dissozn. equil. A part of the hydration envelope of an ion is removed at higher temp..." -- H. Newcombe, CA 49, 8670 (1955).
285. Wicke, E., and Eigen, M.: Bemerkung zu der vorangehenden Mitteilung von E. Hückel und G. Krafft, "Untersuchungen über den Einfluss der Ionengrossen auf das thermodynamische Verhalten von Elektrolytlosungen." Z. physik. Chem. (Frankfurt) 3, 178-182 (1955).

Reply to Hückel and Krafft (1955).

286. Wicke, E., and Eigen, M.: Erwiderung auf die voranstehende Notiz von Hückel und Krafft. *Z. physik. Chem. (Frankfurt)* 5, 312-322 (1955).

Reply to Hückel and Krafft (1955).

Wicke, E.: see Eigen, M.

Wienecke, R.: see Burhorn, F.

287. Wigner, E.: On the interaction of electrons in metals. *Phys. Rev.* 46, 1002-1011 (1934).

"The energy of interaction between free electrons in an electron gas is considered. The interaction energy of electrons with parallel spin is known to be that of the space charges plus the exchange integrals, and these terms modify the shape of the wave functions but slightly. The interaction of the electrons with antiparallel spin contains, in addition to the interaction of uniformly distributed space charges, another term. This term is due to the fact that the electrons repel each other and try to keep as far apart as possible. The total energy of the system will be decreased through the corresponding modification of the wave function. In the present paper it is attempted to calc. this "correlation energy" by an approx. method which is, essentially, a development of the energy by means of the Rayleigh-Schrodinger perturbation theory in a power series of e^2 ." See also F. Bloch, *Z. Physik* 57, 545 (1929).

Winter, E.: see Kroepelin, H.

288. Wohlfarth, E. P.: The influence of exchange and correlation forces on the specific heat of free electrons in metals. *Phil. Mag. (series 7)* 41, 534-542 (1950).

"The effect on specific heat of including exchange terms in the expression for the electronic energy of a free electron gas is discussed. Previous work is considered; the only full discussion (Koppe 1947) contains a number of algebraical errors. When these are corrected the theoretical expression for specific heat becomes, for sodium, $C_e = \gamma T / (8.9 - 1.7 \log_{10} T)$, over a wide temperature range, γ being the Sommerfeld factor. (§2) This relation is in disagreement with observation, due to the approx. implied in the use of a one-electron wave function. In §3 Landsberg's tentative suggestion (1949) for estimating the effects of correlation forces is considered in relation to the present problem, a screened rather than a simple Coulomb potential being used in the exchange integral..."
[See P. T. Landsberg, *Proc. Phys. Soc. (London)* A62, 806 (1949).]

289. Woolley, H. W.: Thermodynamic properties of gases at high temperatures, I. Chemical equilibrium between molecules, atoms, and atomic ions considered as clusters. *J. Research Natl. Bur. Standards* 61, 469-490 (1958).

"The equilibrium thermodynamic properties of gaseous mixtures at high temperatures are treated by an extension of the cluster theory of Ursell, omitting the assumption of additivity of pair energies. An effective p.f. is introduced, which is a convenient function in expressing the increase of the p.f. for the entire gas due to the joining together of the parts of the cluster. The law of mass action and the dependence of second and third virial coefficients upon the cluster integrals for pairs and triples of molecules in a mixture have been obtained therefrom. Extension to a partially ionized gas is made by incorporating Mayer's cluster-based extension of the DH theory."

Woolley, H. W.: see also Beckett, C. W.

York, H.: see Marshak, R. E.

290. Yukhnovskii, I. R.: Binarnaya funktsiya raspredeleniya dlya sistem vzaimodeistvuyshikh zaryashennikh chastits. I. Zhur. Eksptl. i Teoret. Fiz. 27, 690-698 (1954). UCRL Trans. 669 (L).

The pair distribution function for a system of particles interacting with the modified Coulomb potential $\Phi(r) = r^{-1}(1 - e^{-ar})$ is found by solving Bogolyubov's equations (1946). See PA 58, 872 (1955).

291. Yukhnovskii, I. R.: Use of collective variables and treatment of short-range forces in the theory of a system of charged particles. Zhur. Eksptl. i Teoret. Fiz. 34, 379-389 (1958); Soviet Phys. JETP 34, 263-270 (1958).

"Bogolyubov has suggested the study of the 'mixed' problem: the calc. of the p.f. of an ionic system in which the short-range forces are described in coordinate space and the long-range forces are described by means of collective variables. The present paper is devoted to the solution of this problem."

292. Yukhnovskii, I. R.: On the statistical theory of ionic systems. Ukrain. Fiz. Zhur. 4, 167-176 (1959). UCRL Trans. 670 (L).

"An equation is derived for a compact form of energy that is neutral in an entire system of ions, and the binary and ternary distribution functions of this system are considered also. A method of functional differentiation is described, which leads to distribution functions of the Coulomb type, i. e. the so-called short forces are absent." -- W. Jacobson, CA 53, 21067 (1959). Extension of the work of Zubarev (1954).

293. Yukhnovskii, I. R.: Free energy of systems of charged particles. Dokl. Akad. Nauk. S.S.S.R. 126, 557-560 (1959); Soviet Physics Doklady 4, 617-620 (1959).

Shorter version of above paper.

294. Yukhnovskii, I. R.: On the statistical theory of mixed ion-dipole systems of interacting particles. Doklady Akad. Nauk S.S.S.R. 136, 1317-1320 (1961); Soviet Physics Doklady (in press).

Yukhnovskii, I. R.: see also Glauber, A. E.

295. Yvon, J.: Le potentiel thermodynamique à volume constant dans les solutions d'électrolytes forts. *J. phys. radium (series 7)* 7, 93-94 (1936).

"Sommaire: En s'aidant du théorème statistique de Liouville l'auteur établit simplement la formule fondamentale de la théorie des électrolytes de Debye et Huckel relative à la répartition moyenne des ions les uns au voisinage des autres dans une solution en équilibre thermodynamique."

296. Yvon, J.: Les correlations dans un plasma en équilibre. *J. phys. radium* 19, 733-738 (1958).

The pair distribution function is calcd. for a system with Coulomb interactions, using a linearized integral equation and the superposition approximation.

297. Zubarev, D. N.: Vychislenie konfiguratsionnykh integralov dlya sistemy chastits s Kulonovskim vzaimodeistviem. *Doklady Akad. Nauk S.S.S.R.* 95, 757-760 (1954).

Derives by the use of collective coordinates a formula similar to that of Mayer (1950) for the "ring integral" in terms of the Fourier transform of the potential, which reduces to the result of the DH theory for Coulomb interactions.

English translation available from Morris D. Friedman, P. O. Box 35, West Newton 65, Mass.

BIBLIOGRAPHIES ON RELATED SUBJECTS

298. *Aono, T.: Advances in electrochemistry. *Nippon Nogei-kagaku Kaishi* 30, A79-85 (1956).

30 refs., mostly to Japanese work.

299. Bacha, E.: Bibliography on plasma covering the publications of the United States, England, and France within the period 1955 to 1958. NP-7381 (1959).

102 refs. classified by subjects: high temp. aspects, kinetic theory, magnetic fields, microwave measurements, oscillations, plasma conductivity, plasma density, plasma electrons, plasmoids, pinch effect, miscellaneous.

300. Bhatnagar, P. L., Krook, M., and Menzel, D. H.: Dynamics of ionized media. ATI-173970 (1952); Sci. Rept. No. 3, Solar Department of Harvard College Observatory.

99 refs.

301. CERN: List of scientific reports on plasma physics, magnetohydrodynamics, and thermonuclear reactions in the CERN library, December 1, 1958. CERN-Bib-1.

- 170 refs.
302. Chasen, L.: Bibliography on magneto-hydrodynamics. R 60 SD 300; ASTIA Document AD 235868 (1960).
303. Clauser, F. H. (editor): Symposium on plasma dynamics, p. 287-359. Addison-Wesley Publishing Co., Reading (1960).
About 1400 refs. divided into 22 sections.
304. Covert, E. E., and Kerney, K.: A review of the literature of plasma physics. MIT Naval Supersonic Lab. Tech. Rept. 373; WADC-TR-59-486; ASTIA Document AD-227556 (1959).
Includes a classified bibliography of about 600 items.
305. Evans, G. R.: Physics of the ionization processes in air. An annotated bibliography. Lockheed Missiles and Space Division, Sunnyvale, Calif. Report SB-60-40 (1960).
Part I: Formation and production of ions. (278 refs.) Part II: Dissociation and recombination of ions. (76 refs.) Part III: Electron theory. (66 refs.) Part IV: (Other) Secondary processes of ionization. (128 refs.)
306. Frost, F. E.: Bibliography of reports relating to Project Sherwood (controlled thermonuclear reactions) written at University of California Radiation Laboratory, Livermore and Berkeley, 1953-1957. UCRL-5225 (1958).
50 refs.
307. Gleichman, D. L.: A bibliography of LRL (Berkeley and Livermore) unclassified reports on magnetohydrodynamics and plasma. UCRL-6211 (1960).
119 refs.
308. Gmelin Institut für anorganische Chemie und Grenzgebiet: Plasmaphysik. Teil I. Reports and Conferences. (Bibliographische Zusammenstellung). Atomkernenergie-Dokumentation der Bundesrepublik, Frankfurt am Main, Germany. AED-BRD-C-03-1 (1960); also attributed to Max Planck Institut für Physik und Astrophysik.
1647 titles.
309. Gmelin Institut: *ibid.* Teil II. Zeitschriftenaufsätze. AED-BRD-C-03-2 (1960).
1635 titles.
310. Gmelin Institut: Plasmaphysik. Bibliographische Zusammenstellung. Register zu den Heften C-03-1 und C-03-2. Reihe C. Ausgewähltes Schrifttum nach Sachgebieten. AED-BRD-C-03-3 (1960).

311. *Hilsenrath, J.: Sources of transport coefficients and correlations of thermodynamic and transport data in selected combustion problems. II. Butterworths Scientific Publs., London (1956).
312. Hilsenrath, J., et al.: Tables of thermodynamic and transport properties of air, argon, carbon dioxide, carbon monoxide, hydrogen, oxygen, and steam. Pergamon Press, New York (1960).
About 550 refs.
313. Hund, F.: Materie unter sehr hohen Drucken und Temperaturen. *Ergeb. exakt. Naturw.* 15, 189-228 (1936).
46 refs.
314. International Atomic Energy Agency, Vienna: List of references on nuclear energy. Published twice monthly, beginning in 1959.
315. International Atomic Energy Agency, Vienna: List of bibliographies in nuclear energy. Volume 1, numbers 1 (June 1960) and 2 (March 1961) published so far. STI/DOC/11.
316. *Jacobs, J. M., Smelcer, N. K., and Voress, H. E.: Bibliographies of interest to the Atomic Energy Program. TID-3043 (Rev. 1) (Suppl. 2) (in press).
This will include all "Informal Listings" through number 7.
317. Journal of Nuclear Energy: Current papers in plasma physics, accelerators and thermonuclear research. *J. Nuclear Energy (Part C)* 1, 97-104 (1959); 158-169, 277-288 (1960); 3, 48-57 (1961).
318. Journal of Nuclear Energy: Bibliography on magneto-fluid-dynamics. *J. Nuclear Energy (Part C)* 3, 59-92 (1961).
759 refs. to material published through 1959.
155. Kaeppler, H. J., and Baumann, G.: Irreversible stochastic thermodynamics and the transport phenomena in a reacting plasma. AFOSR-TR-57-20; ASTIA Doc. AD-120462 (1956); AF-61(514)-939-1956.
Mitteilungen aus dem Forschungsinstitut für Physik der Strahlantriebe E. V. Verlag Flugtechnik/Ernst von Olnhausen, Stuttgart (1956).
123 refs.
319. Lane, Z. D.: The state of matter at high pressures — a bibliography. 1950-October 1959. UCRL-5926 (1960).
About 220 refs. A revision is in preparation.
320. Lanier, S. F.: Unclassified U. S. Atomic Energy Commission reports on controlled thermonuclear processes. A literature search. TID 3506 (1st rev.) (1957).

55 refs.

321. Lanier, S. F., Scott, R. L., and Scott, T. W.: Controlled thermonuclear reactions. A selective bibliography. TID 3070 (Rev. 1) (1961).

1395 refs.

322. Liley, P. E.: Thermodynamic data for carbon dioxide at high pressure and temperature. J. Chem. Eng. Data 4, 238-241 (1959).

Compilation of published data.

323. Linhart, J. G.: Plasma Physics. North-Holland Publishing Co., Amsterdam (1960).

References at the end of chapters and an additional list of about 230 items.

324. *NATO Advisory Group for Aeronautical Research and Development, Paris: Magneto-fluid-dynamics. Bibliography 1. ASTIA Doc. AD 236361 (1960).

325. Ministry of Aviation, Great Britain, Technical Information and Library Services: Bibliography on magnetohydrodynamics including plasmas. Report TIL/BIB/45; ASTIA Document AD-245267 (1960).

368 refs. from period 1943-1960.

326. Nottingham, W. B., et al.: Bibliography on Physical Electronics. M. I. T. Research Laboratory of Electronics; Addison-Wesley, Cambridge (1954).

327. Office of Technical Information Extension, AEC, Oak Ridge: Controlled thermonuclear processes. TID 3072 (Rev. 1) (in press).

328. Post, R. F.: High-temperature plasma research and controlled fusion. Ann. Rev. Nuclear Sci. 9, 367-436 (1959).

66 refs.

329. Ramer, J. D.: Bibliography of plasma physics and magnetohydrodynamics and their applications to controlled thermonuclear reactions. Engineering and Physical Sciences Library, University of Maryland, College Park (1959).

1700 refs. from the period 1937-1959.

330. Rodabaugh, R.: Plasma physics and magneto-fluid-dynamics. Astronautics information literature search No. 183. JPLAI-LS-183 (1960).

Annotated bibliography containing 903 abstracts and titles, primarily 1957-59.

331. Rompe, R., and Steenback, M.: The plasma state of gases. NP-2149, translated from *Ergeb. exakt. Naturw.* 18, 257-376 (1939).
579 refs.
332. Sabel, C. S.: United Kingdom Atomic Energy Authority and associated British work on controlled thermonuclear reactions. A list of unclassified documents and published articles. Report AERE-BIB-124 (rev. 1) (1960).
418 refs.
333. *Sabel, C. S.: Plasma Oscillations (Bibliography). United Kingdom Atomic Energy Authority Research Group, Harwell, Berks., England (in press).
334. Scott, T. W.: Controlled thermonuclear processes; a selective bibliography. TID 3072 (1958).
(See also: Office of Technical Information Extension.)
335. Spence, B. A.: Bibliography on magnetohydrodynamics, plasma physics, and controlled thermonuclear processes. Avco Mfg. Corp., Report AMP 36; ASTIA Doc. AD 233709 (1959).
About 1500 refs. from period 1925-1959.
336. Stollenwerk, M. J.: Bibliography of plasma physics and related subjects. AEDC-TM-59-5; ASTIA Doc. AD 211155 (1959).
462 refs.
337. Thirsk, H. R.: Electrochemistry. *Ann. Repts. Progr. Chem.* 14, 17-29 (1957).
338. Thomas, M. R.: Bibliography -- Controlled Thermonuclear Processes. LRL Berkeley 1952-1958; LRL Livermore 1953-1958. UCRL 9019 (1959).
About 250 refs.
339. Touloukian, Y. S. (editor): Retrieval Guide to Thermophysical properties Research Literature. Volume I. Thermal conductivity, specific heat, viscosity, emissivity, diffusion coefficient, thermal diffusivity, Prandtl number. McGraw-Hill Book Company, New York (1960).
Book 1. Part A. Guide to substance classification and numerical codes. Part B. Dictionary of synonyms and trade names. Part C. Directory of substances. Book 2. Classified search index. Book 3. Master Bibliography. Author index.

ADDENDA

340. Bahcall, J. N.: Virial theorem for many-electron Dirac systems. Phys. Rev. (in press).

"The virial theorem is derived for a system of N relativistic electrons interacting with each other via electrostatic forces and subject to arbitrary external electromagnetic fields. The results are presented in a form that is useful in perturbation calculations and investigations of nonisotropic systems. The equation of state for a system of N electrons confined to a box is discussed on the basis of the virial theorem."

341. Duclos, D. P., and Cambel, A. B.: On the effective ionization potential of atoms in the interior of a plasma. Z. Naturforsch. 16a, 711-712 (1961).

Comments on the work of Ecker and Weizel (1956).

342. Green, H. S.: Statistical thermodynamics of plasmas. Nuclear Fusion 1, No. 1, 69-77 (1961).

Revised version of 1960 paper.

343. Güntelberg, E.: Untersuchungen über Ioneninteraktion. Z. physik. Chem. 123, 199-247 (1926); CA 20, 3617 (1926).

Discusses hypothesis of linear variation of activity and osmotic coefficients; Brönsted's theory of specific interactions.

344. Hendrick, R. W.: Internal energy and ionization of extremely rarefied air. Report GE-TEMPO-RM58TMP-43. General Electric Co., Technical Military Planning Operation, Santa Barbara, Calif. (1961).

345. Kudrin, L. P.: The equation of state of partially ionized hydrogen. Zhur. Eksptl. i Teoret. Fiz. 40, 1134-1139 (1961); Soviet Physics JETP 13, 798-801 (1961).

"We propose a method for approximate evaluation of the thermodynamic functions of a partially ionized gas, taking into account deviations from ideality. We obtain an equation of state and an ionization formula which is appreciably different from the Saha formula." Includes effect of "the quasi-static microfield of the plasma" which "causes ionization of the upper atomic levels;" also, effect of electrostatic interactions on the ionization equilibrium equation.

346. Laurikainen, K. V., and Euranto, E. K.: Approximate eigensolutions of

$$\frac{d^2\phi}{dx^2} - \left[k^2 + \frac{\ell(\ell+1)}{x^2} - b \frac{e^{-x}}{x} \right] \phi = 0$$

for s-, p-, and d-states. Ann. Univ. Turku. 9, No. 3 (1953).

Solutions of Schrödinger equation with Debye potential. Cf. Harris (1961).

347. Laurikainen, K. V., and Varho, O.: A table of integrals

$$\int_0^{\infty} e^{-ax} \frac{(1 - e^{-x})^p}{x^{q+1}} dx.$$

Ann. Univ. Turku (series A) No. 30 (1958).

Numerical values of integrals arising in previous paper.

348. Noyes, H. P.: Method for calculating the equation of state of AB_2 .
Report GAMD-572, General Atomic (1958).

Ionization equilibrium ignoring electrostatic energy and excluded volumes.

349. Rouse, C. A.: Ionization equilibrium equation of state. Part II. Mixtures. Report UCRL-5695-T, Pt. 3 (1961).

Numerical results for mixtures of H and He.

350. Rozhdestvenskii, I. B.: Thermodynamic and gas-dynamic properties of flowing air downstream of a normal shock wave with allowance for ionization and dissociation. P. 73-85 in Physical Gas Dynamics, Edited by A. S. Predvoditelev. English translation by R. C. Murray and D. R. Phillips; Pergamon Press, New York (1961).

"This paper presents a method for, and the result of, calculating the thermodynamic and gas-dynamic properties of flowing air behind a normal shock wave. The study covered speeds from 4500 to 15,500 m/sec and pressures before shock from 1 to 0.00001 atm. Under these conditions, temperatures of up to 12,000°K and pressures of up to 1000 atm develop behind the shock front A system of algebraic functional equations must be solved, including the continuity equation, the energy and momentum conservation equations and the equation of state. The molecular weights appearing in the equations of conservation of energy and enthalpy and the equation of state are functions of temperature and gas pressure"

351. Sanochkin, Y. V.: Thermal ionization and electrical conductivity of gas mixtures. Zhur. tekhn. fiz. 31, 188-193 (1961); Soviet Physics - Technical Physics 6, 134-137 (1961); PA 64, 520 (1961).

"Magnetohydrodynamic problems demand knowledge of the ionization and the electrical conductivity of gases heated to a high temperature. This is considered for mixtures of monatomic gases, taking account of first and second ionizations. Basic to this is a simple application of the law of mass action, the relative amounts of particles ionized k times depending in a known way on temperature. It is made clear that proper choice of gas mixtures can provide any desired degree of ionization for a given temperature range. By way of example, the degree of ionization attending a shock wave propagated through argon is investigated." (PA).

SUBJECT INDEX

Activity coefficients of electrolyte solutions

6, 7, 19, 21, 24, 25, 26, 33, 47, 50, 53, 62, 64, 74, 80, 86, 96,
97, 98, 99, 125, 128, 131, 132, 149, 151, 180, 187, 203, 215, 222,
224, 237, 238, 246, 282, 283, 343

Air (see also Nitrogen, Oxygen)

17, 30, 36, 48, 105, 116, 135, 136, 142, 146, 147, 175, 226, 249,
257, 281, 305, 312, 350

Argon

24, 28, 312, 351

Association of ions (including Bjerrum, Fuoss theories)

19, 47, 75, 80, 95, 96, 97, 108, 109, 111, 133, 160, 172, 224, 243,
244, 261, 265

Bogolyubov theory

22, 23, 84, 86, 118, 119, 120, 127, 173, 253, 290

Born-Green theory

77, 122, 197, 213, 277, 342

Cluster expansions: see Diagram expansions

Carbon; carbon dioxide

170, 171, 228, 299, 312, 322

Collective coordinates, collective motions, etc. (see also Plasma oscillations)

71, 72, 148, 219, 220, 291, 297

Concentrated electrolyte solutions

16, 19, 25, 26, 27, 33, 74, 75, 80, 82, 86, 99, 119, 123, 125, 150,
151, 162, 168, 189, 216, 253, 284

Correlation energy (ground state energy) of QM electron gas

46, 78, 148, 211, 219, 220, 241, 287, 288

Correlation function: see Pair distribution function

Debye-Hückel theory applied to ionized gases

1, 2, 18, 42, 44, 45, 60, 68, 69, 70, 71, 72, 95, 138, 140, 141, 155,
161, 202, 230, 262, 264

Debye-Hückel theory of strong electrolyte solutions

47, 51, 52, 53, 56, 79, 80, 81, 82, 94, 95, 96, 137, 141, 149, 156,
162, 167, 169, 204, 208, 210, 229, 242, 250, 252, 253, 276

Diagram expansions

2, 32, 58, 59, 86, 117, 127, 132, 178, 179, 184, 187, 188, 198, 199,
200, 201, 202, 241, 268, 271

Dielectric constant, effects of its variation

55, 97, 126, 190, 196

Distribution function (number of positive and negative ions around a
central ion)

6, 7, 64, 74, 75, 83, 86, 282, 295

Distribution function: see also Pair distribution function

Electrolytes — bibliography

50, 80, 82, 86, 134, 137, 298, 337

Excited states of atoms and molecules; partition functions

5, 34, 41, 61, 105, 116, 139, 140, 145, 155, 157, 181, 235, 270

Fluctuations

16, 89, 94, 95, 99, 110, 133, 162, 177, 205, 216

Free energy of system of charged particles

10, 16, 87, 110, 119, 159, 168, 256, 265, 267, 273, 274, 292

Ground-state energy of QM electron gas: see Correlation energy

Helium

156, 349

High pressures — bibliography

12, 313, 319

Historical reviews of electrolyte theory

47, 49, 80, 85, 90, 134, 243, 251

Hydrogen

28, 37, 44, 138, 139, 156, 140, 170, 171, 312, 345, 349

Ionic radius or size: see Size of ions

Ionization equilibrium (see also Saha equation)

11, 24, 39, 40, 48, 73, 76, 91, 92, 93, 95, 105, 113, 116, 138, 139,
142, 144, 145, 147, 155, 170, 171, 173, 181, 183, 192, 217, 226,
227, 233, 240, 249, 262, 264, 275, 289, 345, 348, 349, 351

Ionization potential, variation of

60, 65, 66, 139, 140, 156, 170, 181, 232, 259, 260, 5, 341, 345, 346

Lattice-gas

38, 63

Magnetohydrodynamics: see Plasma

Mayer's theory of ionic solutions

2, 60, 84, 101, 102, 103, 104, 127, 132, 164, 184, 186, 187, 198,
222, 223, 253, 289

Metals, electron theory of

8, 78, 211, 220, 287, 288

Milner's theory

80, 96, 112, 193, 194, 195, 196, 208, 210, 218, 230, 242

Nitrogen (see also Air)

13, 136, 181, 183

Nuclear energy, thermonuclear processes — bibliographies

301, 306, 314, 315, 316, 317, 320, 321, 327, 328, 329, 332, 334,
335, 338

One-dimensional systems

176, 225

Oxygen (see also Air)

13, 35, 181, 247, 312

Pair distribution function, radial distribution function, correlation
function

9, 18, 22, 23, 86, 118, 119, 120, 187, 197, 256, 290, 292

Partition functions of atoms: see Excited states

Plasma oscillations

153, 220, 333

Plasma physics, magnetohydrodynamics — bibliographies (see also
Nuclear energy)

155, 299, 300, 301, 302, 303, 304, 308, 309, 310, 317, 323, 324,
325, 328, 329, 330, 331, 335, 336

Potential of mean (or average) force

29, 84, 163, 164, 184, 186, 187, 213

Pressure, high: see High pressures

Pressure ionization: see Ionization potential, variation of

Quantum effects

18, 39, 44, 45, 46, 57, 58, 59, 60, 69, 93, 122, 138, 161, 166, 178,
179, 192, 198, 202, 221, 271, 287, 288

Quantum field theory methods

3, 4, 32, 106, 107, 241

Radial distribution function: see Pair distribution function

Random phase approximation

211, 219, 220, 258

Relativistic effects

40, 340

Reviews of electrolyte theory: see Historical reviews; Debye-Hückel theory

Saha equation (see also Ionization equilibrium)

5, 39, 76, 113, 170, 191, 192, 209, 227, 231, 233, 234, 235, 240, 269, 275

Size of ions, effect of

14, 60, 79, 80, 83, 96, 100, 124, 125, 133, 137, 150, 151, 152, 160, 168, 172, 197, 203, 216, 238, 239, 244, 248, 282, 285, 286

Sodium chloride

14, 238

Specific heat of QM electron gas near absolute zero

8, 38, 166

Stars (stellar and solar structure)

68, 69, 70, 92, 95, 156, 157, 191, 217, 230, 234, 235, 240, 269

Steam: see Water

Superposition approximation

121, 188, 213

Thermonuclear processes: see Nuclear energy

Virial theorem

87, 88, 115, 193, 236, 279, 340

Water

37, 312

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.