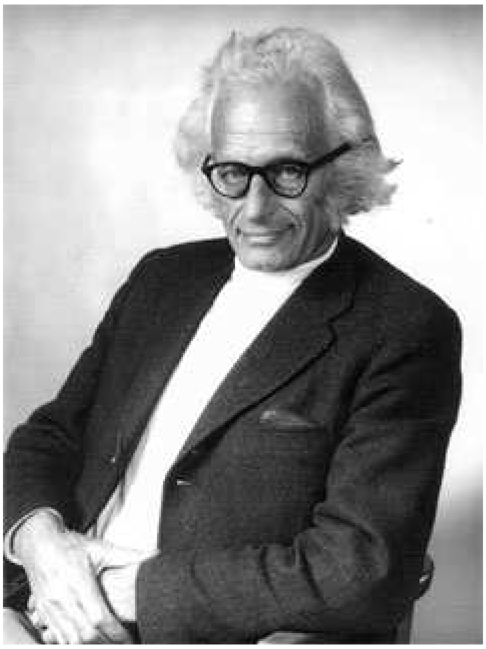

BIOGRAPHY OF Herbert Frohlich (1905 - 1991)

born Dec. 9, 1905, Rexingen, Germany.
died Jan. 23, 1991, Liverpool, England.

Herbert Frohlich (1905 - 1991) was an outstanding German-born British theoretical physicist and a Fellow of the Royal Society (1951). In 1927, Frohlich entered the Ludwig-Maximilians University, Munich, to study physics. He received his doctorate under Arnold Sommerfeld, in 1930. His first position was as Privatdozent at the University of Freiburg. Due to pre-war difficulties in Germany and at the invitation of Yakov Frenkel, Frohlich went to the Soviet Union, in 1933, to work at the Ioffe Physico-Technical Institute in Leningrad. He went to England in 1935. Except for a short visit to Holland and a brief internment during World War II, he worked in Nevill Francis Mott's department, at the University of Bristol, until 1948, rising to the position of Reader. At the invitation of James Chadwick, he took the Chair for Theoretical Physics at the University of Liverpool.

From 1973, he was Professor of Solid State Physics at the University of Salford, however, all the while maintaining an office at the University of Liverpool, where he gained emeritus status in 1976 until his death. During 1981, he was a visiting professor at Purdue University. Herbert Frohlich was Honorary Degree Recipient Doctor of Science, Purdue University in 1981.

Herbert Frohlich was an outstanding twentieth-century physicist who made important contributions to many fields: nuclear forces and meson theory (with the prediction of entirely new particle states), a bilocal extension of the Dirac theory of fundamental particles and quantum mechanics, dielectric loss and breakdown, the theory of metals, 'hot' electron physics, superfluids and the macroscopic quantum state. He is most famous for providing the first successful explanation of superconductivity as the result of an electron-phonon interaction.

H. Frohlich is a co-founder of the microscopic theory of the low-temperature superconductivity.
He published a few seminal papers:
1. Theory of the Superconducting State. I. The Ground State at the Absolute Zero of Temperature

Phys. Rev. 79, 845–856 (1950)

Abstract.

In Bloch's theory of electronic conductivity the scattering of electrons by lattice vibrations is connected with the absorption or emission of vibrational quanta. As in field theories this gives rise to a self-energy which can be calculated by application of perturbation theory. The most interesting term as a result of the Pauli principle has the form of an interaction between electrons in momentum (k) space. The interaction between two electrons whose energy difference is small compared with their energy has a most interesting angular dependence. Roughly speaking, it is repulsive for equal energies but different directions of k, and attractive otherwiso. If strong enough it leads in the ground state to a distribution in momentum space which is different from the normal (Fermi) distribution. If this is the case then excited states exist in which some (\Delta Z} electrons in view of their interaction in momentum space are concentrated in a narrow region in k-space. These states are stable in the sense that it requires energy to remove one of the electrons. Their energies are higher than the ground state by a term proportional to (\Delta Z)^2.

The condition that the above-mentioned ground state (identified with the superconducting state) is realized requires that the interaction between electrons and lattice vibrations exceeds a certain value. With the help of the theory of high temperature conductivity, this condition can be expressed in terms of the resistivity \rho at O C. It is found that \rho n \nu^5/3 (1/n = atomic volume; \nu = number of free electrons per atom) must exceed a value depending on universal constants only. If \nu = 1 is assumed, all monovalent metals except lithium do not satisfy the required condition, but most superconductors do. The energy difference between the normal and the superconducting state at absolute zero is about ms^2 (s = velocity of sound) per electron. It has thus the correct magnitude corresponding to a temperature of a fraction of a degree absolute. No application to higher temperatures or to the influence of external fields has been made yet.

2. On the Theory of Superconductivity: The One-Dimensional Case.

Proc. Roy. Soc. Lond. A, 6 May 1954, vol. 223 no. 1154, p.296-305..

Abstract.

The one-dimensional case of free electrons interacting with lattice displacements is solved by a self-consistent method. It is found that for a certain range of the interaction parameter a single sinusoidal lattice displacement is strongly excited in the lowest level of the system. Its wave-length is such as to create an energy gap in the single-electron energy spectrum with all states below it filled, and all above it empty. This periodic lattice displacement plays the role of an 'inner field' and leads to periodic fluctuation in the electronic density in such a way that the two stabilize each other. In an infinite medium described by a periodic boundary condition they are not fixed absolutely in space, but only relative to each other. Excitation of electrons across the gap leads to a decrease in both the electronic density fluctuations and the width of the gap. The whole system, electrons plus lattice displacements, can move through the lattice without being disturbed provided the velocity *v* is sufficiently small. The inertia of this system is equal to that of all electrons augmented by a term due to the lattice displacements. Elastic scattering of individual electrons which normally leads to the residual resistance

is impossible if v is sufficiently small. The linear specific heat of normal electrons is eliminated and replaced by an exponential term.

3. Isotope effect in superconductivity.
Proc. Phys. Soc. A 63, p.778 (1950).
(A short note which was related to two experimental papers:
C.A. Reynolds et al.
Superconductivity of isotopes of mercury.
Phys. Rev. 79, p.487 (1950).
E. Maxwell. Isotope effect in the superconductivity of mercury.
Phys. Rev. 79 p.477 (1950).)

He elaborated and developed further the concept of POLARON (bound electron-phonon state - Frohlich polaron) in ionic crystals.
A conduction electron in an ionic crystal or a polar semiconductor is the prototype of a polaron. A polaron is a quasiparticle composed of a charge and its accompanying polarization field. A slow moving electron in a dielectric crystal, interacting with lattice ions through long-range forces will permanently be surrounded by a region of lattice polarization and deformation caused by the moving electron. Moving through the crystal, the electron carries the lattice distortion with it, thus one speaks of a cloud of phonons accompanying the electron. The induced polarization will follow the charge carrier when it is moving through the medium. The carrier together with the induced polarization is considered as one entity, which is called a polaron.
Herbert Frohlich proposed a model Hamiltonian for this polaron through which its dynamics are treated quantum mechanically (Frohlich electron-phonon Hamiltonian). For long-wave longitudinal (optical) phonons this electron-phonon interaction is characterized by the dimensionless coupling constant \alpha.
For many ionic crystals the relation \alpha >> 1 holds. In this case the charge carriers are dressed in a phonon cloud. These carriers are called *polarons.* They may have a large radius (Rp >> a) (where a is the lattice constant), in which case they are large polarons or a small one (Rp << a). Research on large polarons began long before research on small polarons, on the conjecture by Landau. The theory of large polarons was developed actively by Pekar, N.N. Bogoliubov, S.V. Tyablikov, H. Frohlich, and later R. Feynman.
see: H. Frohlich, "Electrons in lattice fields". Adv. Phys. 3, 325 (1954).
G.C. Kuper , G.D. Whitfield (eds.) "Polarons and Excitons". Oliver and Boyd, Edinburgh (1963).
Polarons in Ionic Crystals and Polar Semiconductors. J.T. Devreese (ed.), Amsterdam, North-Holland, (1972).
T.K. Mitra, Ashok Chatterjee and S. Mukhopadhyay, Polarons, Phys.Rep. Vol.153. P.91 (1987).
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H. Frohlich was a pioneer in introducing quantum field theory methods into solid-state physics. Indeed, the concept of Frohlich polaron basically consists of a

single fermion interacting with a scalar Bose field of ion displacements.
H. Frohlich, H. Pelzer, and S. Zienau, Phil. Mag. 41, 221 (1950).
These innovative ideas were developed independently in a brilliant way by N.N. Bogoliubov and collaborators:
N. N. Bogolyubov, Ukrainian Math. Zhurnal 2, 3 (1950).
N. N. Bogolyubov, Fortschr. Physik 4, 1 (1961).
S. V. Tyablikov, Zh. Eksp. Teor. Fiz. 18, 1023 (1948).
S. V. Tyablikov, Dokl. Akad. Nauk USSR 6, 3 (1950).
S. V. Tyablikov, Dokl. Akad. Nauk SSSR 81, 31 (1951).
S. V. Tyablikov, Zh. Eksp. Teor. Fiz. 21, 17 (1951).
S. V. Tyablikov, Zh. Eksp. Teor. Fiz. 21, 377 (1951).
S. V. Tyablikov, Zh. Eksp. Teor. Fiz. 23, 381 (1952).
S. V. Tyablikov, Fiz. Tverd. Tela 3, 3445 (1961).
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V. A. Moskalenko, P. Entel and D.F. Digor. Phys.Rev. B. Vol.59. P.619 (1999).
For a review see the book:
N. N. Bogolyubov and N. N. Bogolyubov, Jr., Aspects of Polaron Theory (Fizmatlit., Moscow, 2004) [in Russian].

Frohlich proposed a new fundamental idea which is known as a theory of *Frohlich coherence.*
Reference:
H. Frohlich, Long Range Coherence and Energy Storage in Biological Systems, Int. J. Quantum Chem., v.II, 641-649 (1968)
Coherence is a matter of phase relationships, which are readily destroyed by almost any perturbation. There are several distinct but very closely interrelated uses of the term "coherence" in physics: 'pure states' are coherent and many-particle states may exhibit macrosopic quantum coherence. Two of these share in common that a quantum wavefunction informs the evolution of a physical system as a whole.
The Frohlich effect is a paradigm of how quantum coherence can exist and play a physical role at biological scales. Herbert Frohlich, one of the great pioneers in superstate physics, described a model of a system of coupled molecular oscillators in a heat bath, supplied with energy at a constant rate. When this rate exceeds a certain threshold then a condensation of the whole system of oscillators takes place into one giant dipole mode, similar to Bose-Einstein condensation. Thus, a coherent, nonlocal order emerges.
Because this effect takes place far from equilibrium, Frohlich coherence is in that sense related to the principles underlying the laser (another pumped, coherent system). But what can this coherence accomplish? Frohlich emphasized the lossless transmission of energy from one "mode" to another.

See recent excellent Review paper in the journal INFORMATION:
Aurea R. Vasconcellos, Fabio Stucchi Vannucchi, Sergio Mascarenhas and Roberto Luzzi, "Frohlich Condensate: Emergence of Synergetic Dissipative Structures in Information Processing Biological and Condensed Matter Systems". Information (2012), 3(4), 601-620; doi:10.3390/info3040601.

Frohlich published a few books and numerous reserch papers and review articles.
Books:
[1] Herbert Frohlich. Elektronentheorie der Metalle. (Struktur und Eigenschaften der Materie in Eigendarstellung, Bd.18). (Springer, 1936, 1969)
[2] Herbert Frohlich. Elektronentheorie der Metalle (Ann Arbor: Edwards Brothers, First US edition, in German, 1943) ISBN 1114566489
[3] Herbert Frohlich. Theory of Dielectrics: Dielectric Constant and Dielectric Loss (Clarendon Press, 1949, 1958)
[4] Herbert Frohlich and F. Kremer. Coherent Excitations in Biological Systems (Springer-Verlag, 1983)
[5] Herbert Frohlich, (ed.) Biological Coherence and Response to External Stimuli (Springer, 1988) ISBN 978-0387187396
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[1] T. W. Barrett and H. A. Pohl, Energy Transfer Dynamics: Studies and Essays in Honor of Herbert Frohlich on His Eightieth Birthday (Springer-Verlag, (1987)) ISBN 978-3540175025
[2] G.J. Hyland and P. Rowlands (eds), Herbert Frohlich FRS: A Physicist Ahead of his Time. (University of Liverpool (2006), 2nd edition (2008).) ISBN 978-0-906370-57-5
This book describes Herbert Frohlich's holistic outlook which led him to the brilliantly daring introduction of the concepts of modern theoretical physics, in particular that of coherence, into the open, dissipative systems encountered in biology. The potentially massive significance of this development is only now being fully considered.
The Symposium brought together physicists and biologists, particularly those who either knew Frohlich personally or collaborated with him at some stage during his long and illustrious life, not only to reflect on past glories, but also to evaluate the impact of his legacy on present developments in physics and biology. To this end, ten invited speakers covered the different fields in which Frohlich contributed to significantly to our understanding, thereby influencing future developments.

There are a few places where the biography of Herbert Frohlich can be found. Wikipedia electronic Encyclopedia(http://en.wikipedia.org/) , an article Herbert_Frohlich.

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