Walter Kohn and the Rise of Condensed Matter Physics

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- Prehistory and History

Solid State Physics:

Crystal Structure (> 1911, von Laue and Bragg)

Specific Heat of Solids (Einstein,1907; Debye,1912)

Paramagnetism of Metals (Pauli, 1926)

Squalid State Physics (Pauli, ~1930)

In 1951 or so, Niels Bohr had not heard of the phrase ‘solid state physics’

Condensed Matter Physics: (Physics of condensed matter, which is mostly solid, but can also be a dense liquid ; ~ 1966 or so)

For the last three decades or so, at present, and perhaps in the foreseeable future, the most active area of Physics, e.g. in terms of

the fraction of physicists globally working

the connection with other areas of science

number of grand challenges

number of papers published and pages

Even the number of Nobel Laureates

(Out of 45 laureates after 2000, 22 are in CMP)

The old English saying

'Lies, damn lies and statistics'

has a lot of truth

Why did this happen?

Applications? (e.g. the cell phone, the TV display)

Backend of many parts of science?

Emergence?

Many people also made it happen.

Starting after the Second World War,

a number of talented people

i) made ingenious use of many experimental tools originally developed during (and perhaps because of!) the world war; the process of expansion is going on, remarkably

ii) who were at home in the ‘new physics’ deepened and broadened the subject amazingly

- Walter Kohn was one of the seminal figures in this transformation, through
- His own personal example of research in the field
- His work with students and associates
- His influence through these and through the institutions he was associated with

It is fortunate for the field that very different types like Walter Kohn and Philip Anderson (and somewhat earlier, Lev Landau and Neville Mott) led in invigorating this field ;

it is a good sign for the long term health of the subject

I would like to present a personal picture of Walter Kohn in this perspective

- The work for which Kohn is most famous

(and for which he was awarded the Nobel Prize in 1998) , namely Density Functional Theory, is being discussed by real experts.

I will talk about some of the other things in his journey

- Early life
- Early education in Mathematics and Theoretical Physics, with a Masters from Toronto
- Graduate work at Harvard (PhD, 1948, with Schwinger, on variational methods)

Acquired a reputation there that he knew solid state physics (e.g. Van Vleck...., taught one of the first courses on the subject, at Harvard, and then at Carnegie)

- One of the earliest papers he wrote on solid state physics pointed out (in effect) the fact that if the electron-lattice coupling is very strong, the original lattice structure is unstable

  (Kohn and Vachaspati, 1951)

- From 1952 to 1960, he was at the Carnegie Institute of Technology (now Carnegie Mellon University). The work here went a long way in building the foundations of our present understanding of the electronic behaviour of solids
- He spent summers in Bell Telephone Laboratories (1952-1966), the best place for solid state physics in the world for a long time; he credits this as turning him into a professional from an amateur.

The Carnegie period (1952-60)

- Variational method forelectronic energy band structure (1954, the Korringa Kohn Rostoker method)

(Is there an efficient and accurate method of finding the energy levels of electrons moving in condensed matter, e.g. in a periodic solid?)

- Effective mass theory for electrons and holes in semiconductors (1955-1959; with Luttinger))
- (Properties of semiconductors, basis of all electronics in our age, are determined by electrons and holes arising from donors and acceptors which 'dope' them.) Can one describe what happens in terms of 'effective' masses for carriers? How does one confront such a theory with experiment?

- Purely quantum mechanical theory of electrical transport (1957; with J M Luttinger)
- Singularities in phonon spectra associated with electron Femi surface (1959, Kohn anomaly)
- The nature and description of electronic states in solids (also with coulomb interactions between them, and in the presence of external magnetic fields). Can one describe electrons which are moving all over, as superpositions of states which are very local? How well? (1956 onwards; often with Luttinger)
- Theory of the insulating state (last publication,1964)

Quantum mechanically, what is the most basic characteristic of the insulating state wavefunction?

Students in this phase themselves emerged as world leaders , e.g. James Langer

- **UC San Diego, La Jolla (1960 -79)**

La Jolla became one of the very best places for solid state physics, with a galaxy of stellar practitioners, with great students, postdocs, and visitors.They spread out all over; the field came of age, in depth and size and reach

- Theory of the insulating state (1964))

Quantum mechanically, what is the most basic characteristic of the insulating state wavefunction?

- Density Functional Theory of electronic structure (1964-65; with Hohenberg, and with Sham)

For a system of many electrons interacting with each other and with ions etc., the lowest energy (ground state energy) depends uniquely and only on the local electron density n(r) ;the exponentially high wave function wall is irrelevant

- With a large number of advances in the approach, in computer power, etc., this has become the method of choice for determining the best arrangement of electrons in atoms, molecules, condensed matter materials, molecular complexes, etc..

  (Chemistry, biology, materials science....)

- Superconductivity in a fluid of electrons with only coulomb repulsion between them (1966;with Luttinger)
- Theory of metal surfaces (1971; with Lang)

How are electrons distributed near the surface of a metal ? Deep inside, the density is large. Well outside, there are no electrons.

What size of the energy which keeps the electron inside the metal (work function)?

The first modern look at these questions

- **Phase as a leader** (1979 onwards)
- Founding Director of the Institute of Theoretical Physics, Santa Barbara (1979)

The first of its kind; the success of its innovative activities over a broad range of physics is seen from the number of institutions all over the world that explicitly or implicitly imitate it

Towards the end of the 20th century, the editors of the Reviews of Modern Physics invited him to write an 'Essay on Condensed Matter Physics in the 20th Century'

- Advocate of sustainable energy ; executive producer of the video 'Power of the Sun' (2006 or so)

(with Alan Heeger, another Nobelist, and John Cleese the British actor (of Monty Python fame) as narrator)

- 'Nobel prize-winning scientist developing eyeglasses and computer aids to correct visual distortions experienced with AMD'. (Review of Optometry, 2013).

Thank you