筑波大学
University of Tsukuba

Condensed Matter Seminar
物性論セミナー

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Electron in the field of magnetic charge : Tight binding solution and mapping on a realistic physical system

Prof. Yshai Avishai
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Prof. Avishai has been staying with us at the University of Tsukuba about two month until the end of March. In this opportunity, he is willing to give a talk on his recent research. The talk is divided into two. The first part is introductory and we welcome very much for non-specialists such as non-condensed matter graduate students. After taking a short break, he will continue to present the detailed results for people interested in. The surprising connection between the two parts comes at the end of the second part.

The detail of the talk is described in the next page.

今回イスラエルから筑波大学の国際連携プロジェクトの一環で筑波大学に滞在されているAvishai先生にセミナーをお願いいたしました。セミナーは2部構成で前半部分は、非専門の学生の皆さんにもよくわかるようなお話をお願いし、詳しい議論は後半部分にとお願いいたしました。学部および大学院学生の皆さん、特に物性理論以外の皆さんの参加を歓迎いたします。

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Electron in the field of magnetic charge: Tight binding solution and mapping on a realistic physical system

Yshai Avishai (in collaboration with Jean Marc Luck)

Seminar at the physics department, Tsukuba University, March 2012

It was shown by Dirac about 80 years ago that if there is a magnetic charge g leading to a central magnetic field $\mathbf{B} = g\frac{\hat{\mathbf{r}}}{r^2}$, then g must be quantized as $2eg = n\hbar c$ ($n = 0, 1, 2 \ldots$ is the monopole number). The corresponding "hydrogen atom problem" (a spinless electron in the field of a magnetic charge) was solved by Igor Tamm just a few months after Dirac's paper. Here I approach this problem from a "condensed matter point of view" using a tight binding model. The motivation is threefold: First, the physics is rather beautiful and involves interesting relations with spherical geometry and the theory of graphs. Second, the notion of magnetic monopole is quite relevant in condensed matter physics. Among others, it serves as a useful tool for constructing translation invariant many electron wave functions in the FQHE (such as Laughlin's and Moore Read's N electron wave functions). Third, I will show that under some conditions, this seemingly inaccessible system can be mapped on a realistic physical system. When the sites upon which the electron resides and hops form a highly symmetric object, the energy spectrum is calculated analytically as function of n and displays a beautiful pattern, which is entirely distinct from that of the Hofstadter butterfly. The systematics of level degeneracy is unusual and poses some challenges to the theory of point symmetry groups. The spectrum of an electron hopping on the sites of a Fullerene reveals a set of magic (monopole) numbers n_i.

Is this system realistic? Surprisingly the answer is affirmative. To show this, I nvestigate *within the same geometry*, a seemingly completely different system: that of a spin-full electron subject to an electric field of a point charge $\mathbf{E} = q\frac{\hat{\mathbf{r}}}{r^2}$. The sole effect of this field is to generate a Rashba type spin-orbit interaction. The energy spectrum is calculated analytically as function of the (dimensionless) spin-orbit strength and displays rich and beautiful pattern with some unexpected symmetries in which physics and geometry interlace. This mission accomplished, I then expose a remarkable relation between the two distinct physical problems: The energy spectrum in the second system at a certain symmetry point is *identical* with the energy spectrum in the first system at monopole number $n = 1$. Thus, it is principally possible to test the physics of an experimentally inaccessible system (electron in the field of magnetic monopole) in terms of an experimentally accessible one (an electron subject to spin-orbit force induced by central electric field).