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A LETTERS JOURNAL EXPLORING
THE FRONTIERS OF PHYSICS

DISORDERED SYSTEMS

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Order, as embodied in symmetries and conservation laws, is what many physicists are hoping to find in their studies of nature. But disorder, a "state of confusion" according to the current Oxford English dictionary, has its own attractions to scientists, particularly when it can dramatically change the properties of the "ordered" system. The physics literature is full of examples of such behavior. Perhaps the best–known such dramatic change is the celebrated phenomenon of Anderson localization, so-called after P.W. Anderson, who initiated the field with the first paper on the subject many years ago. The main point is the following: a solid which would normally be metallic, can be turned into an insulator simply by introducing disorder. This transition from metal to insulator does not happen because of a lack of states in the system, but rather because the nature of these states has been subtly modified by the presence of the disorder; they have become localized, i.e. confined to a region inside the material that is much smaller than the size of the system itself. Hence in a transport experiment, charge carriers entering the material will find the states can no longer accommodate their propagation throughout the entire material – Bloch theory has broken down.

We now understand a lot about Anderson localization. It is clear that the underlying phenomenon is rooted in the wave nature of single particle transport at quantum scales, which leads to self-interference of the waves due to backscattering at the random locations of the disorder. This interference then gives rise, as usual, to regions of destructive and constructive superposition and hence regions of low or particularly large wave amplitudes – the latter corresponding to the localization centres. In spatial dimensions one and two it is hard to avoid scattering off even weak disorder and such low-dimensional systems are known to be fully localized – at least for the "generic" case of uncorrelated disorder.

Deviations from this generic behavior are readily constructed and very often easily found in nature. Correlations in the chosen values of the disorder itself are a first such deviation. They give rise to quantitative and qualitative differences, even allowing the existence of mobility edges – sharp transition points separating extended and localized behaviour and associated transitions into delocalized behavior – in one spatial dimension. Analytic results for such situations are available, particularly when the "disorder" is chosen according to quasi-periodic building rules. Also, non-linear interactions, long-range hopping and quantum chaos of the single-particle waves have been shown to lead to new delocalization phenomena.

Furthermore, the thorny issue of many-body interactions, whether they enhance localization or delocalization, continues to attract much renewed interest. Some of this interest is also driven by analysis techniques such as level spacing and other random matrix methods or multifractal analysis which, when combined with modern numerical approaches, allow unprecedented accuracy and predictive power.

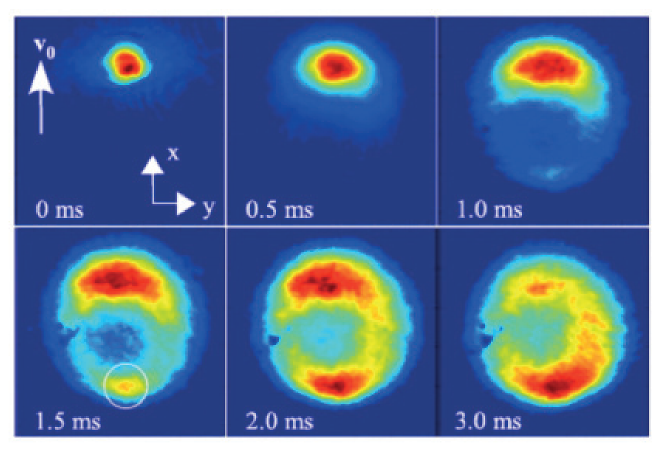

Figure 1 Spatial atomic distribution of a Bose-Einstein condensate in a two-dimensional disorder after 42ms time-of-flight. Each image is an average for different disorder configurations.[1]

The last ten years have brought new experimental techniques into existence that allow the direct and spatially resolved measurement of the quantum waves. Previously, most experiments were of the transport type, where contact of a sample at source and drain allows measuring the response of the system to an external probe (an electric current in most cases) – a rather indirect way of accessing information of the behavior of the wave inside the sample. New types of quantum probes such as scanning microscopes and scanning tunneling spectroscopy now allow the direct measurement of suitable electron wave inside a sample itself – as long as the electron system of interest is close to a surface.

Even more dramatic, advances in cold-atom physics allow the controlled preparation and direct study of the dynamics of matter waves in a suitably engineered disorder. This has given further renewed new impetus to the field beyond the questions traditionally studied in condensed matter systems. But also some of the deep and still open questions of disordered systems – such as the afore-mentioned interplay of disorder and interactions - have been revived. Also, the changes in the properties when the particles are no longer fermionic but bosonic or even a mix of both can now be investigated.

In addition to the atomic gases mentioned before, localization effects in new materials such as, e.g. graphene (of course), topological insulators, DNA-based wires, iron-based superconductors and even metamaterials attract much attention. Equally important have been the advances in applied localization physics, where waves such as sound and heat waves as well as light are being studied more thoroughly for possible applications in optics, heat flow devices and acoustics.

Hence at 65 years of age, when most humans thinks of retirement, the Anderson localization problem is still very much alive with new insights gained on a regular basis. The papers included in our compilation show the wide breadth of the research that has taken place since 2008 in EPL alone.

[1] Labeyrie, G. et al. Enhanced backscattering of a dilute Bose-Einstein condensate. *EPL* **100**, 66001 (2012).

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