Experimenting with free space electron vortices

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Vortex phenomena are fascinating areas of research in almost all fields of physics covering the range from the ultra-small to ultra-large. In this conference, vortices are often related to the quantum state that describes the phenomena of superconductivity in matter and lead to a rich set of experimentally observable phenoma and insights for designing new materials and devices.

In this talk, I will give an overview of experiments with vortex phenomena occurring in single electron quantum states of accelerated electrons in free space. We make use of a customized transmission electron microscope that serves as an electron-optical bench providing a beam of coherent single-electron states. Making use of a range of methods, we readily transform these electron states into states carrying a pre-defined orbital angular momentum (OAM) while still being able to localise them to the atomic scale. In this way we produce electron states that have similarities with electron states in atomic orbitals, having similar spatial extension and OAM properties. We explore the basic properties of such electron beams and demonstrate that many of the effects present in superconductivity, e.g. Landau levels, also occur here and lead to interesting possibilities to measure properties of materials interacting with such beams. Indeed, the selection rules for the scattering of vortex electron beams with atoms provides ways to measure magnetism in materials. Explorations in the role of the quantum state on the interaction with atoms and materials is currently pushing us into the direction of a versatile programmable phase plate for electrons, which will allow full control over the quantum state of the electrons and provide a way to prepare and project states onto any basis of choice. We will explore the potential for quantum measurements that this brings and compare the benefits with respect to more conventional measurement setups in the electron microscope.

References

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