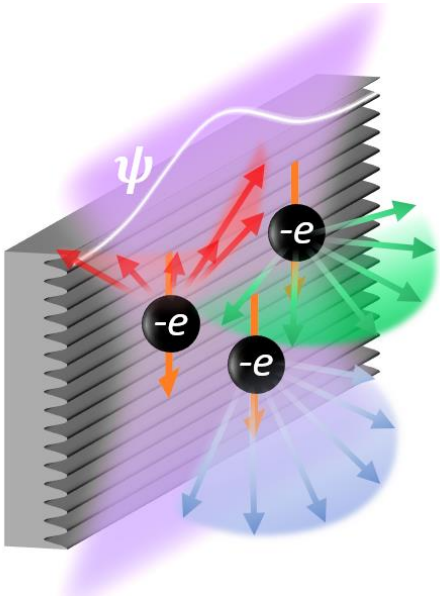
Observing the quantum wave nature of free electrons through spontaneous emission



One of the most intriguing concepts in quantum mechanics is the wave-particle duality. A famous example of this is the electron two-slit experiment: when an electron with a wide wavefunction passes through two slits, its wave properties are manifested by creating interference fringes on a far screen. However, the particle properties are revealed by placing a detector right after the slits, causing detection in only one of the slits and never in both simultaneously.

Despite its long history, this duality remained a source of discussion and debate to this day. In particular, should **spontaneous emission of light from a free electron** depend on its wave properties or on its particle properties?

The group of authors from Tel Aviv University (Israel) and the Technion (Israel) addressed this question in a paper that appeared recently in *Physical Review Letters* [1]. The performed an experiment comprising a wide electron wavepacket that spontaneously emits light when passing near a metallic grating, in a process known as the Smith-Purcell effect [2]. By observing the emitted light from the interaction of the electron with the grating, this experiment answers the riddle: upon emission of a photon, does the electron behave as a point particle – emitting spatially diverging light, or as a wide and non-localized wave comprising a continuous charge distribution – emitting spatially collimated light?

The authors show that Smith-Purcell spontaneous radiation is the result of a localized interaction, meaning that the electron interacts with the grating as a single point-charge, with the probability of finding it at a certain position given by the square modulus of its wavefunction, and *not* as a continuous charge distribution. This conclusion for the *spontaneous emission* experiment is in contrast with contemporary *stimulated emission* and absorption experiments, such as photon-induced nearfield electron microscopy and high harmonic generation, where the opposite picture is necessary to explain the results.

[1] R. Remez, A. Karnieli, S. Trajtenberg-Mills, N. Shapira, I. Kaminer, Y. Lereah and A. Arie, "Observing the quantum wave nature of free electrons through spontaneous emission," *Physical Review Letters* **123**, 060401 (2019). https://doi.org/10.1103/PhysRevLett.123.060401

[2] S. J. Smith and E. M. Purcell, "Visible Light from Localized Surface Charges Moving across a Grating," *Phys. Rev*. 92, 1069–1069 (1953).