Spontaneous magnetization in a non-magnetic interacting metal

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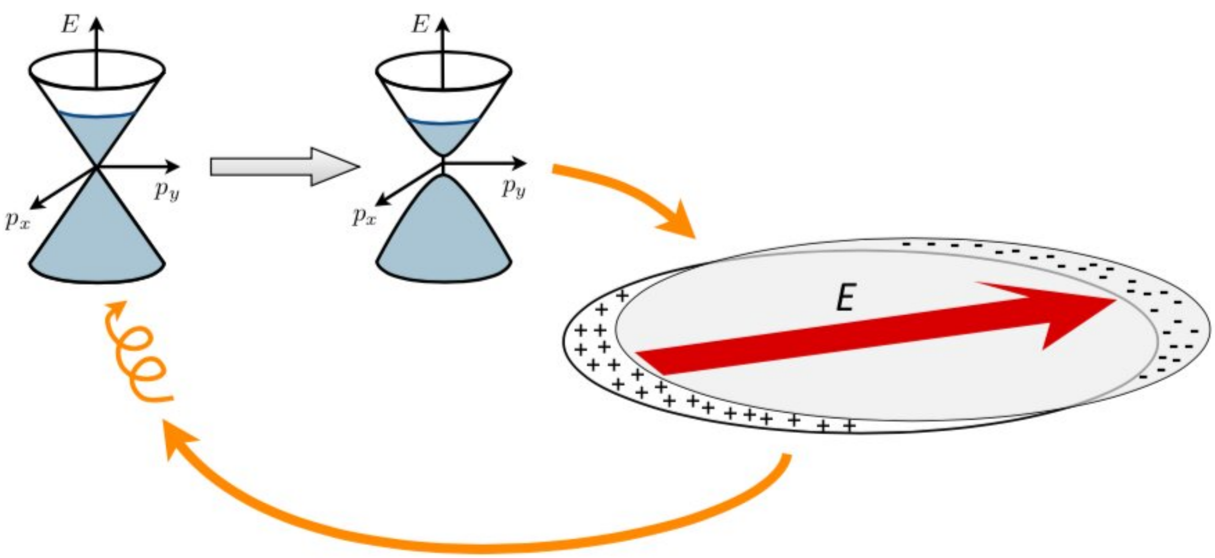

When a plasmon wave is excited in a metal, the displacement of electric charges is accompanied by the formation of a strong, oscillating 'internal field' (red arrow). This oscillating internal field acts back on the material itself to change its electronic properties, which in turn changes the character of the plasmonic wave itself. Credit: Rudner & Song.

Over the past decade, numerous physics studies have explored how oscillating electric fields produced by lasers or microwave sources can be used to dynamically alter the properties of materials on demand. In a new study featured in *Nature Physics*, two researchers at the University of Copenhagen and Nanyang Technological University (NTU), in Singapore, have built upon the findings of these studies, uncovering a mechanism through which a non-magnetic interacting metal can spontaneously magnetize.

"Recent experiments in nanoplasmonics have shown that when the electrons in nanoscale metallic systems are collectively excited, they can, in fact, produce extremely intense oscillating electric fields all on their own," Mark Rudner, one of the researchers who carried out the study, told Phys.org. "In light of this observation, we set out to uncover what new phenomena could arise when these 'internal fields' within a material feed back to change the properties of the material itself."

The internal fields that Rudner refers to are intense oscillating electric fields that originate from charge oscillations in a metal, known as plasmons. Plasmons are often used to confine light to length scales far below its original wavelength at a nanoscale, as well as to guide its propagation through devices. The detailed behavior of a plasmon (e.g. the frequency it oscillates at, its chirality, etc.) is directly dependent on a material's properties, such as its electronic bandstructure.

"Typically, these material specifics are thought to be fixed quantities of the material chosen; to get a different type of plasmon one would conventionally have to use a different material," Justin Song, the other researcher involved in the study, told Phys.org. "We wondered if there was a way to get around this constraint. Importantly, if a plasmon's strong internal fields could modify a material's electronic band structure thereby changing the material's properties, it would also transform the plasmon as well, setting up a feedback loop enabling the plasmon to take on new types of behavior."

Once they realized that oscillating internal fields in an excited material can change its electronic properties, Rudner and Song set out to demonstrate this concept within the simplest possible setup. They thus decided to study nanoscale graphene disks, as graphene is a widely available and high-quality material that has favorable characteristics for observing this effect. Using this setup, they demonstrated the conditions under which feedback from the internal fields of collective modes could trigger an instability towards spontaneous magnetization in the system.

"We theoretically analyzed how the plasmons in a graphene disk morphed under linearly polarized irradiation and found that when the light intensity was low, the plasmon should oscillate along the same direction as the light polarization," Song explained. "However, above a critical intensity, our theoretical analysis indicated that the plasmon can spontaneously choose to rotate, acquiring a handedness that was not originally present in the metallic disk nor the irradiating light. In this way, the plasmons acquire a 'separate life' (spontaneously choosing a chirality) distinct from both that of the material that hosts it (the metallic disk) as well as that of the light field that is driving it (the linearly polarized irradiation)."

In their study, Rudner and Song showed that the collective modes of driven systems can sometimes take on a 'life of their own," exhibiting unique and spontaneous symmetry-breaking phenomena that are independent of the underlying equilibrium phase. Although the researchers illustrated this principle using nanoscale graphene disks, it also applies to other materials.

"The key observation when carrying out our analysis was that, from the point of view of an electron within a material, an electric field is an electric field: it doesn't matter whether this oscillating field was produced by a laser shining on the material from outside (as previously studied), or collectively by all of the other electrons within the material itself," Rudner said. "This opens a world of new possibilities wherein internal fields produced by collective excitations in materials may lead to a variety of new phenomena."

As Rudner and Song explain, the properties of collective modes, such as plasmons, are generally 'locked' to their host material. Interestingly, however, their observations prove that plasmons can defy this 'locking' to their host material. In other words, their study shows that plasmons can have phases that are distinct from the underlying material hosting them.

The study carried out by Rudner and Song offers new valuable insight into how oscillating electric fields within materials, particularly non-magnetic metals, can alter some of their properties. So far, the researchers have concentrated on the distinct phases of plasmons, but they are now planning to examine other collective modes that might exhibit similar symmetry-breaking phenomena.

"We hope to see our predictions borne out in experiments in the near future," Rudner said. "On a theoretical level, there are many fundamental questions to explore about the nature of the non-equilibrium spontaneous symmetry breaking that we predicted, as well as extensions to other physical systems and types of behaviors. We also plan to investigate possible applications of this phenomenon, for example in optoelectronics."

More information: Mark S. Rudner et al. Self-induced Berry flux and spontaneous non-equilibrium magnetism, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0578-5
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