The Meissner effect in superconductors: emergence versus reductionism

J. E. Hirsch
Department of Physics, University of California, San Diego, La Jolla, CA 92093-0319

The Meissner effect, the expulsion of magnetic field from the interior of a metal entering the superconducting state, is arguably the most fundamental property of superconductors, discovered in 1933. The conventional theory of superconductivity developed in 1957 is generally believed to fully explain the Meissner effect. We will review the arguments that support this consensus, rooted in the concept of emergence. However, recent work has shown that there are questions related to momentum conservation in the process of magnetic field expulsion that have not been addressed within the conventional theory. Within a reductionist approach, it has been proposed that those questions can only be resolved by introducing physics that is not part of the conventional theory, namely that there is *radial motion of electric charge* in the transition process. This is consistent with the behavior of classical plasmas, where motion of magnetic field lines is always associated with motion of charges. We review how this approach explains puzzles associated with momentum transfer between electrons and ions in the Meissner effect. Whether or not radial charge motion is associated with the Meissner effect has fundamental implications regarding superconductivity mechanisms in materials and regarding strategies to search for new materials with higher superconducting transition temperatures. Therefore, adjudication of this question is urgent and important.

Contents

I. INTRODUCTION

The two most characteristic properties of superconductors are zero resistance and the Meissner effect, the expulsion of magnetic fields from the interior of a material becoming superconducting. The Meissner effect is the property that differentiates superconductors from "perfect conductors", which are materials that conduct electricity with no resistance but do not expel magnetic fields. Perfect conductors do not exist, but can be regarded as a limiting case of "very good conductors", that do exist. What makes superconductors *qualitatively* different from very good or perfect conductors is precisely the Meissner effect. When the effect was experimentally discovered in 1933 [1] it triggered a very rapid advance in the field, because it was completely unexpected and because it is such a fundamental property. We can reasonably expect that such a fundamental property of superconductors should reflect fundamental physics underlying the superconductivity phenonenon. What that fundamental physics is is currently under contention and is the subject of this review.