

Expert Opinion

Electrons and bursting waterworks

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The Expert Opinion is written by a distinguished scientist and presents his/her personal view on important and relevant new results of research, highlighting their significance and putting the work into perspective for a broader audience. Please send comments to pss@wiley-vch.de or to the author.

The text by Dirk van der Marel refers to the Rapid Research Note by M. Matlak et al., Chemical potential induced phase transitions, published in this issue of phys. stat. sol. (b) **241**, R23 (2004).

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A yearly ritual before the winter returns is the emptying of the waterworks outside our homes. It is a well-known fact that water, when it freezes, expands, usually with destructive consequences for the waterworks, that is to say, if we have forgotten to empty them. The freezing of water is a typical example of a phase transition. When water turns into ice, the so-called chemical potential of the water molecules changes, causing fewer molecules to occupy the same amount of space.

Electrons in a metal usually form some kind of liquid. Unlike water molecules, each electron carries a small amount of charge and, due to the spin, also a small amount of magnetic moment. The charge and the spin allow the electrons to order in a large diversity of states of matter, such as ferromagnets, superconductors, antiferromagnets, etc. Electrons can even crystallize, thus prohibiting the conduction of electrical currents, a phenomenon which is known as Wigner crystallization. These forms of ordering disappear when we warm up the electrons to a characteristic temperature, the so-called transition temperature, T_c . Just as for the water/ice transition, the chemical potential of the electrons changes at T_c [1]. That such a change should take place is firmly rooted in a set of fundamental equations of thermodynamics, the so-called Ehrenfest relations [2]. Accordingly, the temperature dependence of the electron chemical potential is directly related to dT_c/dn , where n is the density of the electrons. This means that just like for the water in the waterworks, the electron density wants to change when a phase transition occurs: the electrons try to spill over the boundaries of the material in which they are contained!

A water pipe has only two options: Either it is strong enough to sustain the pressure of the compressed ice, or it bursts. For electrons in a solid this is different: When the electron liquid begins to expand, a charge layer builds up on the sample surface, giving rise to an electric field which exactly balances the change in chemical potential [3]. Hence the sample does not burst, but instead the charge at the surface changes. This causes a change of the electrical fields outside the sample which, in principle, can be measured. Earlier attempts to measure these small changes of electric field were either utilizing a vibrating capacitance bridge [4], or electrochemical cells [5, 6]. The disadvantage of the former is that it requires very clean and stable sample surfaces, which is only possible under ultra high vacuum conditions. For the latter method the sample must be immersed in an aqueous solution during the measurements, which imposes considerable limitations on the possible range of substances and temperatures.

Recently Matlak and Pietruszka have proposed a much simpler experimental method [7], which utilizes the fact that a change of the chemical potential of the sample can affect the electrical resistivity of an electrode in contact with the sample. This effect is obviously extremely small, but changes in resistivity

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can be measured with a very high accuracy, so in principle this could work. In a paper which appears as Rapid Research Note (www.pss-rapid.com) in the present issue of *physica status solidi (b)*, Matlak and collaborators claim to have observed just this effect at the magnetic phase transition of a number of different magnetic substances [8]. The observed changes of the resistivity are indeed quite small. Clearly this new effect needs to be analyzed in more quantitative detail before we can have absolute certainty about its microscopic origin. However, irrespective of its microscopic origin, Matlak and collaborators have discovered a new experimental method for studying phase transitions which appears to be sensitive and easy to implement. Undoubtedly this will soon be further investigated in many other laboratories around the world.

References

- [1] If the chemical potential itself changes abruptly, this is called a first order phase transition. However, in many cases only the rate of change as a function of temperature jumps from one value to another at T_c . This is a so-called second order phase transition. The examples given in the paper of Matlak and collaborators [8] are of the latter variety.
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