'elastic' — that is, when the collision is not associated with any change in the particle's energy. This means the Wiedemann–Franz law should always hold true at a temperature of absolute zero when all scattering becomes elastic. As the temperature tends to zero, the ratio of thermal conductivity to electrical conductivity divided by temperature tends to a constant value. This statement is true for all metals tested to date.

The twentieth century saw the development of the 'band structure' theory of electron behaviour in solids, which treats electrons as individual free entities. Surprisingly, this theory — which ignores the strong electrostatic repulsion between the electrons — has been successful in describing the main electronic properties of various metals. In 1956, Lev Landau revealed the reason behind its success. He formulated the concept of a 'Fermi liquid', in which the interacting electrons are replaced by 'quasiparticles' that interact but can still be treated as particles (in this case, fermions) with the same spin and charge as a free electron. The only difference between quasiparticles and electrons is that the quasiparticle has a modified mass, which reflects the size of the electronic interactions.

It is hard to exaggerate the fecundity of Landau's theory. Most metallic elements and compounds are Fermi liquids. There are even exotic metals — in which strong interactions between electrons create Landau quasiparticles several hundred times heavier than a free electron — that fit within the band-structure theory. But do other types of strongly interacting electronic systems exist? In other words, are Fermi liquids only one of many correlated-electron systems found in nature? This question has been haunting condensed-matter physicists for the past 30 years.

The copper oxides challenged the Fermi-liquid picture almost as soon as they were discovered. And we are still far from understanding the elementary excitations (akin to quasiparticles) found in the metallic ('normal') state of these compounds. These superconductors have unusual origins. The parent compound is a Mott insulator, which should be a conductor according to the standard band-structure theory, but fails to conduct because of strong repulsive interactions between the electrons. A metallic state can be created in a Mott insulator by injecting it with conducting electrons — for example, by altering its chemical structure (chemical doping). This is how a copper oxide insulator is turned into a copper oxide superconductor.

But the Fermi-liquid picture cannot easily explain the metallic state of a doped Mott insulator. For example, angle-resolved photoemission data indicate that Landau quasiparticles appear only in the superconducting state[3]. These and other experimental findings have led to alternative descriptions of the elementary excitations in these systems. One recurrent feature of these 'non-Fermi-liquid' theories is the separation of two of the most fundamental properties of an electron: its 'spin' and its charge. In the words of P. W. Anderson, "the electron falls apart" in such a way that different excitations are responsible for carrying its spin and charge. But this idea has been difficult to check experimentally because there is no established method for directly probing transportation of the electron spin.

Hill and colleagues[2] approach this mystery from a new angle. They investigate the transport of heat in the normal metallic state of a copper oxide superconductor at millikelvin temperatures. In all superconductors, whether low- or high-temperature, the zero-resistance state can be destroyed by applying a high enough magnetic field (the size of the field is determined by the superconducting transition temperature). The copper oxides usually require fields that are too high to achieve experimentally, but the compound studied by Hill *et al.* has a transition temperature of just 20 K, so superconductivity can be removed by applying a much smaller magnetic field. Hill *et al.* measure the thermal and electrical conductivity of the 'normal' state of their compound (at low temperatures and under applied fields), and discover a clear departure from the Wiedemann–Franz law. They show that there is no correlation between thermal and electrical conductivity at very low temperature. Instead, the heat conductivity is consistently greater, although the excess suddenly vanishes below 0.3 K. Because the Wiedemann–Franz law is a natural consequence of the Fermi-liquid picture, this spectacular violation has immediate consequences for understanding the elementary excitations in copper oxides. Taken at its face value, it means that charge and heat are not carried by the same type of electronic excitations, so there may indeed be some sort of spin–charge separation in these materials.

This is really just the beginning. We need to repeat the measurement on superconductors with different amounts of chemical doping to determine exactly when the Fermi-liquid picture breaks down. Moreover, studies of other compounds at higher magnetic fields may indicate whether the excess heat flow is associated with electron spin, as suspected. Most pieces of this huge puzzle of modern condensed-matter physics are still waiting to be put into place. ■

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NATURE

100 YEARS AGO

The practicability of effecting the purification of town sewage on the large scale by bacterial agency has now been abundantly proved. The process has passed beyond the experimental stage, and must now be acknowledged as the only method which can convert the putrescible matter of sewage on the large scale into inoffensive and harmless substances. Accordingly all trustworthy information respecting the results which have been arrived at from the lengthy experimental trials, and from the application of these results on the large scale, will be welcome to public sanitary authorities, and perhaps even still more acceptable to the professional advisers of these bodies. The treatise under review has been written by one who has carefully watched the progress, and who has had a long and varied experience, of bacterial treatment. The book is, therefore, undoubtedly worthy of careful perusal and consideration by those who are responsible for disposing of the sewage from houses, villages or towns.

From *Nature* 12 December 1901.

50 YEARS AGO

Teletherapy units using radium are limited in usefulness by the low radiation intensities produced by the small amounts of radium which can be used. To secure an adequate dosage-rate, the distance between the source and the tumour cannot be more than a few centimetres, and therefore the dose delivered to the skin lying between the source and the tumour is much higher than that delivered to the tumour. The dose-rate below the surface, expressed as a percentage of the dose-rate at the skin, decreases very rapidly with increasing depth. Thus the percentage depth-dose is influenced primarily by the inverse square law, and one of the chief advantages of high-energy radiation, namely, its small attenuation by the tissue between the source and the tumour, is not realized. Any attempt to obtain an improvement in the depth-dose by increasing the amount of radium, and correspondingly improving the ratio between the source-to-tumour distance and the source-to-skin distance, is limited by the high cost of radium, and by the required increase in the volume of the source. If the diameter of the source is increased, it is harder to get a well-defined beam; if the thickness in increased, much of the radiation is lost by absorption within the source.

From *Nature* 15 December 1951.