as rapidly as other cities including Mumbai (India), Dhaka (Bangladesh) and Lagos (Nigeria) (Fig. 2). Full implementation of the PAHO strategy is needed in the megacities and the surrounding regions to stop measles transmission. If this proves to be impossible, new approaches such as development of new vaccines for administration in early infancy may be needed.

Grenfell and colleagues[2] show that, in the pre-vaccine era, waves of measles infection moved away from London at a speed of around 5 km per week and were evident up to 30 km away from the city. There was a time lag between the peak in the originating urban centre and its arrival in the periphery — the lag was greater for smaller and more distant towns. Given this pattern, it is tempting to think that the extent of measles outbreaks can be controlled by vaccination ahead of the epidemic. But attempts to control outbreaks show that once a wave of infection has been established, it is difficult to stop it through selective vaccination. Often the intervention comes too late or, if it is in time, the 'wave' of measles infection still sweeps over and around the 'breakwater'. Current recommendations are that measles outbreaks should be prevented rather than controlled after they have started[8]. But vaccination in areas next to districts in which an outbreak occurs may be effective if high coverage of all susceptible age groups is achieved.

From Grenfell and colleagues' results, it might seem that concentrating on cities would be an effective vaccination strategy (although this is not something they themselves propose). This approach — based on the idea that cities are the key disease reservoirs — has been tried in Africa, and has not worked. In the late 1990s, Burkina Faso and Mozambique conducted mass vaccination campaigns, targeting children of preschool age in the largest cities with the aim of preventing spread to more remote rural towns and villages that health services found hard to reach. In both countries, the urban campaigns were associated with some reduction in the size of the expected epidemic in the city but were unsuccessful in preventing disease spread to rural areas[9]. The urban campaigns still left enough susceptible city dwellers to result in an epidemic, and then human migration seeded the periphery, leading to large outbreaks elsewhere.

These examples reinforce the need for universal vaccination against measles for all children regardless of where they live. The sheer number of people moving around for business or pleasure, in addition to forced migrations, make importation of measles a common occurrence: achieving and maintaining high population immunity by vaccination throughout an entire country is the only proven way of preventing large outbreaks.

The results in Grenfell *et al.*'s paper should stimulate activity in at least two areas. First, it is likely that the city-to-village dynamics that they document for measles also apply to other common human diseases. Among them are some that can be prevented by vaccines (rubella, mumps, varicella and hepatitis A) and some that, as yet, can't (those caused by respiratory syncitial virus, rotaviruses and adenoviruses), and influenza, which has pandemic potential but is vaccine-preventable. Better characterization of the patterns of disease transmission in space and time could offer unique opportunities for prevention: in particular, more research is needed on the effect of long-range jumps of infection that occur, for example, with air travel.

Second, the new work highlights the value of careful collection, analysis, dissemination and storage of disease-surveillance information. Accurate records of measles cases were kept in England and Wales long before vaccination against the disease was introduced, and Grenfell and colleagues' sophisticated time-series analyses were possible only because of the geographically detailed and complete nature of the data sets. We would be wise to strengthen the disease-surveillance systems in both developed and developing countries, and to include collection and storage of clinical specimens as part of that endeavour. Not only is such information essential for immediate disease control, but it will also make possible future research with analytical or laboratory methods yet to be devised. ■

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High-temperature superconductivity

Charged with smuggling heat

Kamran Behnia

Good conductors of heat are usually good at conducting electricity. So the discovery that electrons in a superconductor can carry an unauthorized amount of heat at low temperatures raises many questions.

Copper oxide compounds are noteworthy for the relatively high temperatures (up to 160 K) at which they lose their resistance to electrical currents and become superconducting. This was discovered by Bednorz and Müller[1] in 1986, and gave birth to the field of 'high-temperature' superconductivity. High temperatures aside, the unconventional nature of the superconducting mechanism in these materials has puzzled researchers ever since.

In 1986, few would have guessed that a shock wave produced by that scientific earthquake would reach an old realm of solid-state physics 15 years later and shake one of its most fundamental concepts. But on page 711 of this issue, Hill *et al.*[2] report that, at low temperatures (close to absolute zero, or −273 °C), a copper oxide material in which the superconducting state has been suppressed violates the Wiedemann–Franz law. This universal law relates two basic properties: the ease with which a solid conducts heat and charge. As this is the first time a material has been found that deviates from this law, it reveals, yet again, that high-temperature superconductors are far from being understood.

Almost 150 years ago, Wiedemann and Franz discovered a remarkable correlation between the thermal and electrical conductivities of various metals — good conductors of electricity are also efficient conductors of heat. At room temperature the ratio of the two conductivities was found to be very similar for a broad range of metals. Several decades and a scientific revolution later, this ratio was linked to two fundamental constants: the quantum of electrical charge, e, and the 'quantum' of entropy, k_B (better known as the Boltzmann constant). Roughly speaking, entropy measures the disorder of electrons and is the microscopic origin of 'heat'.

The fundamental mechanism behind the Wiedemann–Franz correlation is easily grasped. The propagation of electrons in a crystal is impeded by the presence of any imperfection (impurities or defects). So there is always a maximum finite distance that an electron can travel before being scattered. Because the electron carries both heat and charge, scattering will affect thermal and electrical conductivities in the same way. This is strictly true only if the scattering is '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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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.