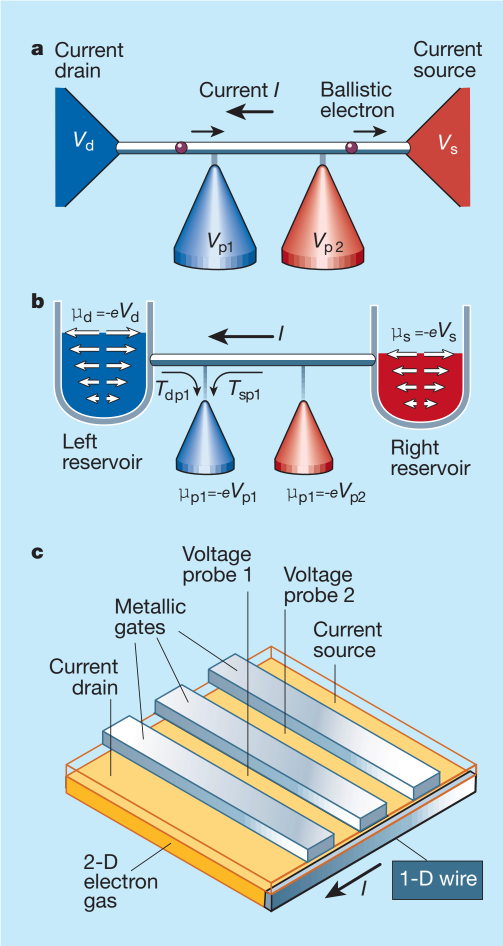

Figure 1 **Measuring resistance in one-dimensional wires.** a, **An ideal one-dimensional conductor with two current terminals and two voltage probes, which draw no current. The two terminal resistance, R_{2p}, is defined as $(V_s - V_d)/I$, whereas the four-terminal intrinsic resistance, R_{int}, is given by $(V_{p2} - V_{p1})/I$.** b, **Landauer's concept[2] of a perfect one-dimensional wire, in which electron reservoirs with unbalanced electrochemical potentials ($\mu = \mu_s - \mu_d$) provide current source and drain. Note that $\mu = -eV$, where μ is the electrochemical potential, e is the fundamental electric charge and V is the voltage. The measured resistances depend on the transmission and reflection probabilities of the electrons within the conductor. In particular, for a four-terminal intrinsic resistance to be zero, the transmission and reflection probabilities from the left and right reservoirs into a voltage probe must be nearly equal ($T_{sp1} = T_{dp1}$). This is only possible if the conductor is ballistic and devoid of obstacles.** c, **The perfect one-dimensional wire created by de Picciotto *et al.*[1] with two current and two voltage terminals created from the same two-dimensional electron gas.**

wire, de Picciotto *et al.* use a precise semiconductor growth technique called cleaved edge overgrowth[7] to grow alternate crystalline layers of GaAs and AlGaAs in orthogonal directions, which form a neat edge. Even more remarkably they have succeeded in attaching non-invasive voltage probes to the minuscule wire. The GaAs/AlGaAs sheet forms a two-dimensional electron gas, and the authors place metallic electrodes on the surface to isolate the one-dimensional wire from the rest of the sheet (Fig. 1c). When negative voltages are applied to these electrodes they deplete the two-dimensional electron gas beneath them but preserve the one-dimensional wire along the edge. The width of the metallic electrodes defines the length of the isolated wire. The separation between the electrodes also creates two narrow strips in the two-dimensional electron gas that act as voltage probes.

This set-up allows both four-terminal and two-terminal measurements to be made on the same wire. In order to measure the intrinsic resistance, it is essential that the voltage probes do not disturb the current flow. With a one-dimensional wire this is usually impossible, but in their system de Picciotto *et al.* can tune the effect of the voltage probe until it is almost non-existent. They show that whereas the intrinsic resistance measured between the non-invasive voltage probes vanishes, the two-terminal resistance of about 13 kΩ can be directly attributed to the current contacts. This non-zero contact resistance indicates that there is a minimum resistance for the passage of electricity regardless of how perfect a wire may be.

It would be interesting to explore the possibility of circumventing the limitations imposed by the presence of contact resistances. One can imagine measuring the electrical properties of one-dimensional conductors using a contact-free method, such as capacitance coupling, to induce charge motion. The results of studies like that of de Picciotto and colleagues will apply equally to carbon nanotubes and other one-dimensional systems, and will become increasingly important as electronics gets ever smaller. ■

Albert M. Chang is in the Department of Physics, Purdue University, West Lafayette, Indiana 47907-1396, USA.
e-mail: yingshe@physics.purdue.edu

1. de Picciotto, R., Stormer, H. L., Pfeiffer, L. N., Baldwin, K. W. & West, K. W. *Nature* **411,** 51–54 (2001).
2. Landauer, R. *IBM J. Res. Dev.* **1,** 223–231 (1957).
3. Webb, R. A., Washburn, S., Umbach, C. P. & Laibowitz, R. B. *Phys. Rev. Lett.* **54,** 2696–2699 (1985).
4. Buttiker, M. *Phys. Rev. Lett.* **57,** 1761–1764 (1986).
5. van Wees, B. J. *et al. Phys. Rev. Lett.* **60,** 848–850 (1988).
6. Wharam, D. A. *et al. J. Phys. C* **21,** L209–L214 (1988).
7. Pfeiffer, L. N. *et al. Appl. Phys. Lett.* **56,** 1697–1699 (1990).

Daedalus

Scroll-reading

The ancient world guards its secrets well. In the buried ruins of Herculaneum, the many scrolls that make up the library of Philodemus wait to be deciphered. Sadly, the scrolls have been carbonized, and it is extremely difficult to unwind them for normal reading. Daedalus now has an idea.

The nuclear magnetic resonance imager should make it possible to scan such scrolls without unrolling them. Interpreting a scrolled image would take very clever software, but it seems feasible. More problematically, could the best modern machines resolve the lettering? Fortunately, the basic pixel of a coil is curved, like that of a scroll, and also extends in depth, again like a scroll. With luck, a scroll rotated in a superconducting coil, and slowly moved in and out of it, should yield up its lettering to a controlling scholar.

Of course, nobody believes in the Wisdom of the Ancients any more. No matter what amazing statements or beliefs are found in antique libraries, letter files or rubbish dumps, the job of scholars will be to decipher, translate and interpret. Simple letters inviting somebody to a party, or denying an allegation, may be handled most easily; documents claiming to be part of a revelation will give a lot more trouble.

The basic problem, however, is what nucleus to look for in the magnetic-resonance output. Ancient inks were based on soot (carbon), which might have little contrast with the surrounding carbonaceous papyrus or vellum, unless it contains germanium or potassium, from coal or wood. It might be better to examine the vehicle (gum), which would have more hydrogen, and more mobile hydrogen, than the lettering itself. If so, preliminary steaming of the scroll could help. If any of the inks were based on black iron gallate, the signal from paramagnetic iron should be easy to detect. Either way, Daedalus reckons that some sort of contrast change between ink and background could be detected by the instrument and highlighted by its software, enabling a scholar to read the entire scroll without the pain of unwinding it.

Even the problem of dating the find may become tractable, if the changes in the ink, vehicle and substrate turn out to be fairly predictable in time. And if in the future a better method becomes available, why, the scroll is still there, undamaged by clumsy attempts to unroll it. David Jones