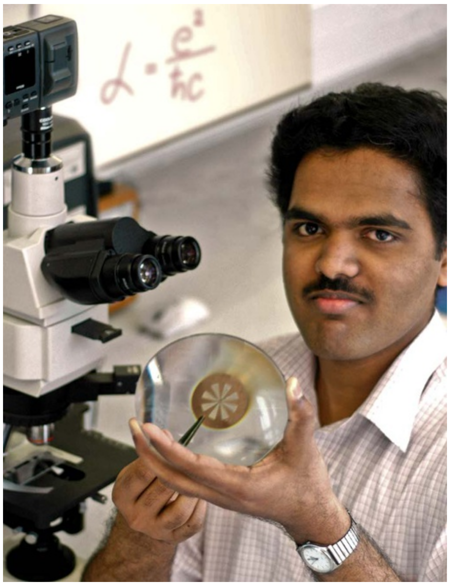
measure for measure

When lost in a multiverse

Wonder material graphene makes metrology practical and relaxed, says **Andre Geim**.

Imagine you are completely lost, as occasionally I am at meetings, wondering whether your colleagues belong to the same universe. Under such circumstances, graphene can come to the rescue. Yes, graphene again… After 15 years of working with this material, I understand and share the sentiment.

If you do find yourself lost at one of such meetings, take a small piece of graphene deposited on a transparent plastic film and have a look at the Sun through it. By evaluating the contrast between areas covered and not covered with graphene, one can estimate how much light it absorbs. The difference in contrast should be 2.3% — at least in our Universe. This may sound little but in fact graphene is one of the most light-absorbing materials per unit of thickness. More importantly, 2.3% is not just a random number: it is the value obtained when multiplying π by the fine-structure constant $\alpha = e^2/2\varepsilon_0 hc \approx 1/137$, with e the elementary charge, ε_0 the electric constant, h the Planck constant and c the speed of light in vacuum. The first experiment to determine graphene's optical transparency was done exactly as described above, by looking at white light through a small graphene membrane, taking a photograph and performing a simple image analysis[1]. The picture shows Rahul Nair, a PhD student at the time, posing with a device used in ref. 1 to measure graphene's optical transparency. Within good accuracy, graphene was found to absorb a fraction $\pi\alpha$ of visible light. Nowadays it is possible to buy A4-size graphene deposited on a transparent substrate to do this experiment at home or at school.



LEONID PONOMARENKO

Unfortunately, graphene cannot offer metrological accuracy for α. Calculations showed that the absorption value was actually not as accurate as one would hope for, because graphene's electronic structure actually deviates slightly from the Dirac (linear) spectrum often associated with the material[2]. Moreover, many-body effects (excitonic corrections) lead to additional deviations at short wavelengths. Nonetheless, graphene samples are perhaps adequate for accidental multiverse travellers who can be satisfied with a rough rather than metrological assessment of their sanity.

But what if a visited universe differs from ours by only a tiny bit, say by one part per billion? With a new twist and a larger piece of equipment, graphene can help again. One could then use the quantum Hall effect (QHE) to ensure that α has not changed. The QHE allows measurements of the so-called von Klitzing constant or the resistance quantum $h/e^2 = 1/2\varepsilon_0\alpha c$ with such extreme accuracy that there is no reference left to check against[3]. QHE standards are now compared against each other using different materials exhibiting this phenomenon[4,5]. Graphene is one of them and the latest favourite of metrologists worldwide[4,5], thanks to an extremely robust QHE, enabling metrology at higher temperatures, lower magnetic fields and smaller probing currents than any other material.

In graphene, quantum Hall plateaux can survive up to room temperature[6]. They are also incredibly long as a function of magnetic field, if graphene grown on SiC is used[5]. The latter feature makes it easier to measure h/e^2 accurately. In fact, the plateaux are so long that researchers initially thought that their magnet stopped sweeping because a QHE plateau continued beyond the horizon, with no changes in the signal over 80% of the available (14-tesla) field range[5]. Also, graphene allows extremely high probing currents, before deviations from the ideal QHE become discernible. This places weaker constraints on what type of measurement equipment can be used. The von Klitzing constant in graphene was compared with those observed in other materials. No deviations were observed between different systems[4], proving that the resistance standard is independent of the material used for its realization.

High-cost dedicated magnet systems with complex measurement setups are currently essential to provide QHE metrology. Thanks to graphene, these can soon be compressed into simpler, tabletop and cryogen-free systems. As the rumour goes, soon you will be able to buy a personal resistance standard from Oxford Instruments[5], for just a few bitcoins. From a multiverse traveller's perspective, such a tabletop standard is obviously less comfortable than having one von Klitzing in your pocket — a resistor of 25.8 kΩ, of course — but it can probably be fit into a (large) suitcase and, for instance, shipped to the International Space Station to check for general- and special-relativity corrections to h/e^2, if any. ❐

ANDRE GEIM is at the School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK.
e-mail: geim@manchester.ac.uk

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