necessary only for maturation after sex has been determined. It is tempting to speculate that, by default, gametocytes would develop into females, and that only those gametocytes for which a transcriptional switch at the *md1* locus occurs, resulting in Md1 production, become males. Testing this hypothesis will require a high-resolution temporal analysis of the RNA species at the *md1* locus in sexual precursors in which sex is not yet specified.

Previous research using a method called a plaque assay, in which the progeny cells produced from individual asexual parasites can be visualized, indicates that sex determination occurs at the same time as, or soon after, commitment to sexual conversion[5,6]. By contrast, Gomes *et al.* show that Md1 expression and transcriptional differentiation between male and female gametocytes start at stage II or III of gametocyte development, which is about four days after sexual conversion, suggesting that sex determination occurs instead at this later stage. The results of the plaque assays (from more than 20 years ago), which used antibodies to distinguish between male and female gametocytes, should be revisited by performing the assays with newer technology and tools such as male–female reporter lines, in which different fluorescent proteins are expressed depending on whether parasites are male or female. If the plaque-assay conclusions are confirmed, it will be necessary to reconcile the apparent discrepancy with Gomes and colleagues' results, perhaps invoking molecular events upstream of the transcriptional switch at *md1*. Such events might pre-commit a parasite to become either male or female several days later.

Life-cycle progression in *P. falciparum* is generally governed by the expression of a cascade of transcriptional regulators of the ApiAP2 family[8]. However, for sexual conversion and sex determination, the parasite uses a complex transcriptional switch at the *gdv1* or *md1* genomic regions, respectively. The *gdv1* locus also encodes an abundantly expressed antisense long non-coding RNA, which has been proposed to act as a repressor of GDV1 expression[3]. By contrast, Gomes and colleagues ruled out a repressor role for the *md1* antisense long non-coding RNA, although its precise mechanism of action is unknown. Of note, antisense long non-coding RNAs are also involved in the regulation of another gene family (the *var* genes) with a fundamental role in parasite biology[9] — mediating parasite virulence and evasion of immune responses. Therefore, complex transcriptional switches involving different RNA species encoded in the same locus emerge as a common theme for fundamental processes in malaria-parasite biology that require robust regulation.

The identification of Md1 as the male sex determinant settles a major outstanding question in malaria-parasite biology and raises several questions. Future research should determine the mechanism underlying the transcriptional switch at the *md1* locus that results in expression of the full-length mRNA and Md1 production, and identify the regulator(s) of *md1* expression. This switch probably involves an element of randomness (stochastic processes) because, in a population of genetically identical parasites under the same environmental conditions, some will develop as males and some as females. However, the switch might nevertheless be modulated by environmental cues to dynamically adjust the sex ratio to the optimal level for different conditions[4,10].

Of note, the proportion of parasites that convert into sexual forms (the sexual-conversion rate) is also affected by the environment. Some cues that enhance baseline sexual-conversion rates have been identified, including depletion of specific lipids and exposure to certain drugs[11,12]; however, the mechanism by which these cues result in *gdv1* and *pfap2-g* expression is unresolved. Future research should address the mechanism by which the *gdv1* and *md1* switches respond to the environment.

Another crucial aspect of sex determination now ripe for exploration is the identification of Md1's molecular targets. Gomes and colleagues' work suggests that Md1 contributes to regulating the stability or translation of some mRNAs. Identifying the specific mRNAs that are targeted and the downstream events in which they participate will be needed to gain a full mechanistic understanding of malaria sex determination.

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Condensed-matter physics

Twin techniques narrow search for elusive particles

Manohar Kumar & Chuan Li

A versatile nanowire system has enabled the hunt for particles that could be useful for quantum computers. The platform can be probed with two techniques simultaneously — minimizing the possibility of false-positive signals. **See p.442**

Majorana particles are curious things. They are unusual excitations comprising a pair of half electrons — and they are their own antiparticles. This means that they annihilate each other when brought together, but remain stable when separated. What makes them really intriguing is that they retain a memory of how they move — a property that could be used to store quantum information in solid-state systems. The only problem is that they are tremendously difficult to find, and there have been instances of false-positive detections. On page 442, Valentini *et al.*[1] report a system in which measurements can be made simultaneously using two techniques, reducing the probability of false positives and revealing a simple explanation for a misleading signature.

Although elementary Majorana particles were proposed 85 years ago by Italian physicist Ettore Majorana[2], they are yet to be detected in high-energy physics experiments. However, analogous 'particles' can be engineered in solid-state systems that comprise semiconducting materials combined with some that exhibit superconductivity (zero electrical resistance). This is because the electrons in superconductors have energies that are equivalent to those of their antiparticles, which are called holes in this context. This symmetry enables the formation of states, known as Majorana bound states, at the ends of wires made from these hybrid materials[3].

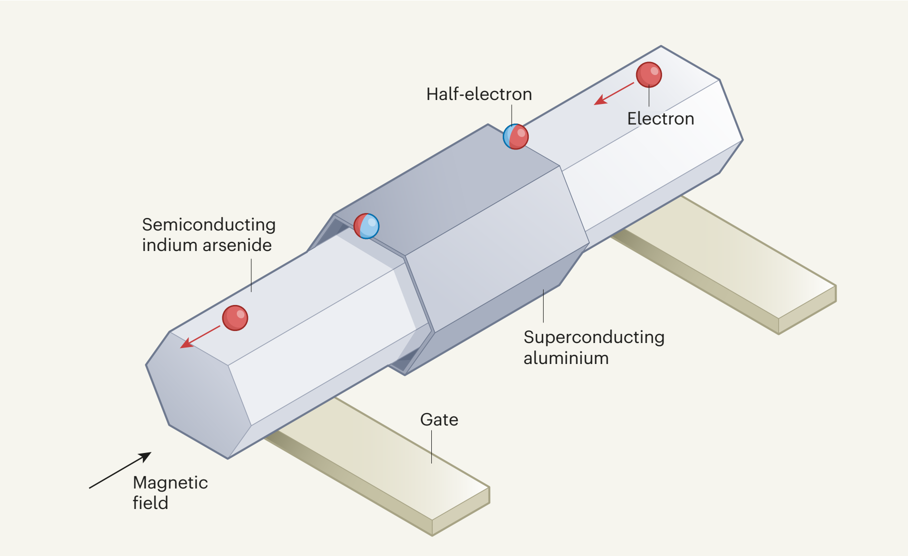

Figure 1 | A nanowire platform for finding elusive particles. Valentini *et al.*[1] fabricated a device comprising a semiconducting indium arsenide nanowire, fully wrapped in aluminium, which exhibits superconductivity (zero electrical resistance). Electrodes called gates were used to tune the device between conditions that are optimal for two types of spectroscopy (tunnelling and Coulomb). By using these techniques on the same sample, the authors probed the device for long-sought exotic quasiparticles known as Majorana bound states, which consist of a pair of half-electrons. These states are expected to form in the presence of a magnetic field, but Valentini *et al.* showed that the spectroscopic observation could also have a simple explanation, and arise in materials that lack these exotic states.

These bound states are quasiparticle excitations, rather than the fundamental particles proposed by Majorana.

These states are also known as Majorana zero modes, because they coincide with a peak in electrical conductance when the voltage applied across the material known as the bias voltage is zero[4]. Such peaks have been observed in semiconductor wires that are partially covered by superconductors, using a technique called tunnelling spectroscopy. However, the measurements depend on the strength of the magnetic field and on another voltage (known as the gate voltage), and this sensitivity makes the results inconclusive[5]. An alternative technique, called Coulomb spectroscopy, has also been used to detect Majorana zero modes, but the interpretation of these results is also still a topic of debate[6,7].

A method for growing the superconducting material aluminium such that it fully covers all facets of a hexagonal semiconducting indium arsenide nanowire has enabled the search for Majorana bound states at a much lower magnetic field strength than that required for probing them in partially covered wires[8]. This is useful, because magnetic fields tend to suppress superconductivity, which is essential for producing Majorana bound states. Applying a magnetic field along the axis of the fully covered nanowires results in a phenomenon known as the Little–Park effect – in which the magnitude of the superconducting behaviour oscillates as a function of the magnetic field, creating 'lobes' in experimental scans of the field-dependent conductance[9]. Majorana bound states are predicted to be generated when material parameters are in some of these superconducting lobes.

Measurements of electron transport are dominated by electron pairs in the lobes, whereas measurements in the resistive regions between the lobes represent mainly single-electron transport. Coulomb spectroscopy is expected to reveal periodic peaks in the conductance corresponding to these two types of transport[10], with the peak corresponding to single-electron transport arising only from a state with energy that is close to zero. If the material hosts Majorana bound states, this energy should decrease exponentially with the length of the wire[6,7]. Such suppression was first reported in partially covered nanowires[6] and subsequently in fully covered nanowires[11].

But the question remains whether these measurements are actually evidence of Majorana bound states, or whether there is some other explanation for the decrease in energy. Valentini *et al.*[12] previously showed that the zero-bias peaks can also signal the presence of quasiparticles known as Andreev bound states, which form when electrons pair with holes. Now, the authors have performed both Coulomb and tunnelling spectroscopy on the fully covered nanowires, obtaining a more complete picture than was possible in previous attempts.

To achieve this, Valentini *et al.* fabricated electrodes, known as gates, at the ends of the fully covered nanowire. This enabled them to control the probability with which electrons would traverse the barrier between the voltage leads and the nanowire. They used these gates to tune the device so that they could access conditions suitable either for Coulomb spectroscopy or for tunnelling spectroscopy. This allowed them to check for the signature of the transition from electron-pair transport to single-electron transport using Coulomb spectroscopy, while simultaneously identifying the zero-bias peak using tunnelling spectroscopy. This transition and zero-bias peak together strongly signal the existence of bound states (Fig. 1).

Despite their exhaustive tunnelling spectroscopy measurements, Valentini *et al.* did not observe any zero-bias peaks, and therefore detected no Majorana bound states. However, their Coulomb spectroscopy revealed peaks with a periodicity indicative of these states, so the two measurements were not consistent. The authors also did not observe the expected exponential decrease in the energy associated with the peaks[6,7]. This implies that the observed transition from electron-pair to single-electron transport is not related to any exotic bound states, and could have a simple origin, making it a false-positive signal for Majorana bound states.

The take-home message is that the zero-bias peak observed in tunnelling spectroscopy and the peak periodicity seen in Coulomb spectroscopy do not necessarily signal the presence of Majorana bound states if they are observed separately on different samples. Experimental set-ups such as Valentini and colleagues' apparatus are, therefore, indispensable for such searches, because they enable the simultaneous testing of both signatures on the same sample. In doing so, they reduce the uncertainty in measurements of the characteristic signals of Majorana bound states.

Fully covered nanowires have one limitation, however: after the semiconductor is covered, the aluminium is chemically etched away in two places to attach the gates. This process could complicate matters by introducing disorder into the crystal structure of indium arsenide. An ideal fabrication technique would be to grow the superconductor selectively on top of the semiconducting wire.

As materials are developed, exploring Majorana physics in different platforms will no doubt provide further insight[13]. Alternative methods[14,15] that can access broader ranges of material parameters than those available to tunnelling and Coulomb spectroscopy could also offer complementary strategies in the search for Majorana bound states. One thing is clear, however: testing these different techniques simultaneously will be crucial to ensuring that false-positive signals are not misinterpreted – a feat that Valentini and colleagues' approach will certainly help us to achieve.

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Ecology

Herbivores drive scarcity of nitrogen-fixing plants

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In mature tropical forests, trees that can capture nitrogen experience high levels of herbivory. This could explain the low abundance of such trees, and demonstrates that herbivores can limit nitrogen availability on land. **See p.483**

Terrestrial ecosystems have a key role in helping to slow the pace of climate change, absorbing roughly one-third of the carbon dioxide emissions produced by human activities since the start of the Industrial Revolution[1]. However, the extent of this uptake of carbon on land is limited by the availability of nitrogen[2] — a phenomenon that has puzzled scientists for decades[3]. On page 483, Barker *et al.*[4] present data to address a long-standing hypothesis[3] that herbivory explains nitrogen limitation.

Several plant species in the legume family, including peas, have evolved partnerships with bacteria that can capture (also termed fix) nitrogen from the atmosphere and convert it into molecules that are the building blocks for amino acids and DNA. Trees that host these symbiotic bacteria (called nitrogen-fixing trees, or nitrogen fixers) have a competitive advantage when nitrogen is in limited supply[5]. Yet, despite this advantage, nitrogen fixers comprise only 5–15% of the trees in mature tropical forests[6]. Solving this paradox will improve our understanding of nutrient cycling in forest ecosystems and will also advance our ability to correctly predict the extent of terrestrial carbon capture[7].

Previous studies examining the puzzle of nitrogen limitation on land have pointed to constraints on the availability of light and nutrients as influencing legume growth and nitrogen-fixing activity. Nitrogen-fixing trees are more competitive than are trees that don't fix nitrogen during periods in which light availability and demand for nutrients are high[8–10], such as the early stages of forest development, or when a large tree falls and creates a gap in the canopy that can be filled. However, in mature tropical forests, these explanations seem insufficient to explain the low abundance of nitrogen-fixing trees. Theory[11] and some experimental studies[12] show that tropical legumes can turn off nitrogen fixation in some conditions, making nitrogen-fixing trees equally competitive with non-fixers[11]. However, if herbivory (Fig. 1) is greater among nitrogen fixers than among non-fixers, this could result in a cost that is sufficient to restrict the growth, survival and abundance of nitrogen-fixing plants in tropical forests.

Barker and colleagues tested whether nitrogen-fixing trees experience higher levels of herbivory than do non-fixers, and modelled the carbon cost of this herbivory. In a field study, the authors examined diverse tree species (23 species capable of fixing nitrogen and 20 non-fixers) growing as understorey seedlings in mature tropical forests in Barro Colorado Island, Panama. Barker *et al.* report that nitrogen fixers are targeted 21% more often by herbivores than are non-fixers, which results in a carbon cost for nitrogen fixers that is nearly twice as high as that for non-fixers. In modelling the carbon cost, the authors considered the loss of carbon in leaf tissue that must be replaced and the opportunity cost that results from that lost leaf material no longer making carbon-rich sugars by photosynthesis. Barker *et al.* suggest that the substantial carbon cost explains why nitrogen-fixing trees are not as abundant as might be expected in mature tropical forests.

Surprisingly, nitrogen fixers' high herbivory rates could not be accounted for by a range of leaf physical and chemical characteristics that the authors examined. At first, this seems counter-intuitive. Several studies, including this one, show that nitrogen fixers have higher concentrations of nitrogen in their tissues than do non-nitrogen-fixing plants, even when

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Figure 1 | Herbivory of leaves on trees in Barro Colorado Island, Panama.