

which is a number comparable to all currently known antibiotic-resistance genes<sup>6</sup>. Thus, this study shows clearly that an extraordinary diversity of antibiotic-resistance genes exists in nature, as suggested by previous analysis of soil microbial communities<sup>7</sup>.

An earlier study<sup>5</sup> from the group presenting the current paper reported the first case of the transfer of several drug-resistance genes between innocuous soil bacteria and human pathogens, highlighting that transfer of genes between such bacteria is possible. But that study included bacterial-enrichment steps that prevent quantification of the extent of such transfer. In the present study, the authors used a method that did not require enrichment and which allowed them to quantify the extent of antibiotic-resistance genes that are shared between soil bacteria and previously characterized bacteria.

They found that only around 0.1% of the identified resistance genes from soil are highly similar (greater than 99% nucleotide identity) to previously detected resistance genes, indicating that there is only limited overlap between the resistance genes of soil bacteria and other bacteria, including those that cause infections in humans (Fig. 1). Although this low overlap does not exclude the possibility of soil bacteria acting as an origin of antibiotic-resistance genes that cause clinical problems, it does demonstrate that only a minute fraction of resistance genes from soil bacteria have been transferred to human pathogens.

Forsberg *et al.* also investigated whether the limited overlap might result from limited transfer of antibiotic-resistance genes within the soil microbial community. If this is the case, specific resistance genes should be stably associated with specific phylogenetic divisions. The authors show that this is correct and conclude that the resistance-gene pool of different soil communities is closely linked to the phylogenetic architecture of those communities. The authors were not able to resolve the phylogenetic architecture beyond the phylum level, and so horizontal transfer of genes within a specific phylum cannot entirely be ruled out. However, they show that soil bacteria, in contrast to human pathogens, have a much lower number of mobilization elements flanking their resistance genes, which supports their hypothesis of limited transfer of resistance genes between soil bacteria. These results are consistent with the hypothesis that there is limited selection for antibiotic resistance within the soil microbiota compared to the selection for antibiotic resistance in human pathogens.

These findings fuel the ongoing question of what is the function of antibiotic-resistance genes in their natural hosts. For instance, the MFS transporter proteins identified by the authors as conferring resistance to a wide range of antibiotic classes may not actually function as antibiotic-resistance proteins in their hosts, but rather in different processes, such as the

transport of other small molecules that may be more abundant than antibiotics in the soil. Similarly, the identified  $\beta$ -lactamase enzymes might serve as cell-wall remodelling enzymes in their natural hosts. The apparent paucity of mobilization elements flanking these genes would suggest that selection for and transfer of resistance functions in the soil is not as strong as in other environments.

Irrespective of the function of these genes in their natural hosts, Forsberg and colleagues' study demonstrates that the soil microbiota harbours an extraordinary diversity of genes that have the potential to confer antibiotic resistance in human pathogens such as *E. coli*. Their findings also suggest that it may not be the availability of genes encoding proteins capable of conferring antibiotic resistance that limits the spread of resistance, but rather the mobilization and transfer of these genes. Functional metagenomic studies of soils that have been exposed to inhibitory concentrations

of antibiotics should be performed to test whether this increases the extent of resistance-gene mobilization. ■

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#### MATERIALS SCIENCE

## Energy storage wrapped up

**Cables and wires are used to conduct electricity, but can they also store energy? The answer is a resounding 'yes', if they are encased by a supercapacitor device — a finding that might open up many applications.**

YURY GOGOTSI

Electrical cables entangle the world, supplying electricity to buildings, machines and electronic devices. The systems currently used to store electrical energy are separate from the cables, and are bulky contraptions often consisting of assemblies of 'supercapacitor' devices. Reporting in *Advanced Materials*, Yu and Thomas<sup>1</sup> describe coaxial cables consisting of a copper core surrounded by a supercapacitor sheath, which can both transmit and store electricity.

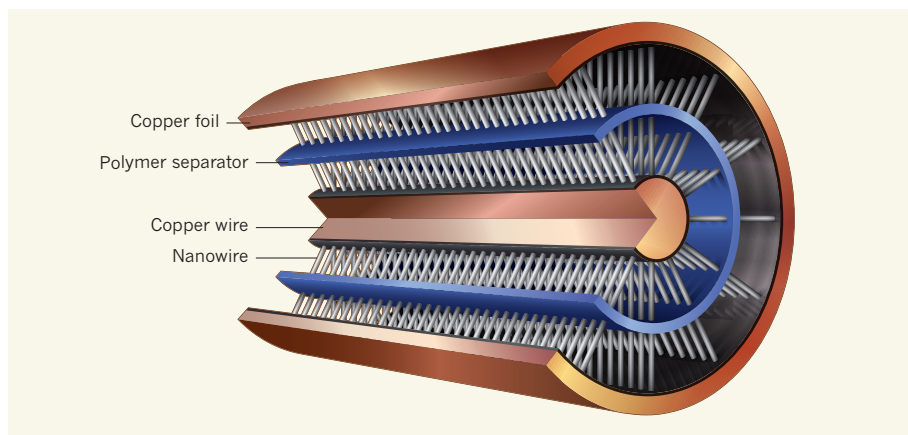
Energy storage in supercapacitors can involve two mechanisms<sup>2</sup>: the formation of a double layer of ions adsorbed on oppositely charged electrode surfaces; and pseudocapacitance, in which fast electrochemical reactions occur at the surface of an electrochemically active material, such as manganese dioxide. Because pseudocapacitance occurs on a large electrode surface, it always takes place alongside double-layer capacitance.

In supercapacitors, charge is stored only at surfaces, and so — unlike in batteries — its availability is not limited by diffusion processes, allowing high power to be achieved<sup>3</sup>. Similarly, because charging and discharging

do not involve a bulk-phase transformation, as they do in batteries, supercapacitors are much more reversible (less energy is lost during a charge–discharge cycle) and have a longer cycle life<sup>2</sup> (up to a million charge–discharge cycles). These properties are desirable for energy-storing cables.

To add capacitive storage to conventional wires, Yu and Thomas effectively wrapped a supercapacitor around a core conductor wire (Fig. 1). They began by growing nanowires of insulating copper oxide perpendicular to the surface of a copper wire, and then coated these nanowires with a gold–palladium alloy, which acts as a current collector for the supercapacitor. An electrochemically active coating of manganese oxide was then deposited on top of the alloy. The resulting brush-like architecture leads to a 100-fold increase in surface area compared with the bare copper wire; a large surface area is crucial for capacitive energy storage. The nanowires serve as a sheath covering the copper wire, and form the first electrode of the supercapacitor.

To construct the rest of the device, the authors coated this electrode with a solid electrolyte (a material that conducts ions, but not electrons, and which electrically connects



**Figure 1 | Energy-storing cables.** Yu and Thomas<sup>1</sup> report cables that conduct electricity through a central wire, but that also store electrical energy in a coaxial supercapacitor. In the authors' design, electrochemically active nanowires project from a copper wire coated with copper oxide (black). The nanowire layer forms the first electrode of the supercapacitor device, and is wrapped in a porous polymer separator. A second electrode — consisting of nanowires as described above, attached to a copper foil coated internally with copper oxide — surrounds the polymer separator. Both electrodes are coated in a gel electrolyte (not shown) before assembly, to ensure that they are electrically connected to each other. (Figure adapted from ref. 1.)

the supercapacitor's electrodes) and a porous polymer separator, and then assembled another tubular electrode around that. The second electrode was made in the same way as the first, except that nanowires were formed on a copper foil, rather than a wire. The resulting material was also precoated with a solid electrolyte before its assembly around the first electrode. The coaxial geometry of the resulting device combines all of the components of a supercapacitor into a single cable and ensures good electrical contact between the electrodes and current collectors. The researchers observed that the core wire can carry current independently of energy storage, at least when low-voltage direct current is transmitted through it.

Yu and Thomas report a high capacitance per unit mass of active material for their device — much higher than that of other pseudocapacitors based on manganese dioxide. However, this was the case only for a small loading of 0.5 milligrams of oxide per square centimetre. The values reported for devices with larger loadings were much smaller, which limits the amount of energy that could be stored in these coaxial supercapacitors. Increasing the amount of stored energy will be essential for practical applications.

Energy-storing cables must be flexible, strong, wear-resistant and well insulated, and no electrode fracturing or short-circuiting should occur on bending. The researchers bent their device at different angles up to 100 times and found that the capacitance was generally stable, although folding it 100 times at 180° led to a loss of about 7% of the initial capacitance. Furthermore, only 1% of capacitance was lost after 5,000 charge–discharge cycles without folding.

Single supercapacitor cells usually produce 1 to 3 volts, and generate direct current. Devices with multiple cells connected in sequence can achieve the 12–24 V needed for applications

such as small electronic devices, humanoid robots and automotive electronics, all of which use direct current. Household applications, however, use higher voltages (110 V in the United States and 220 V in Europe) and alternating current. Supercapacitors are impractical for these applications because of the need for conversion from direct to alternating current, and because about 100 cells would need to be connected in sequence, which would lead to energy losses associated with electrical resistance. Losses would also occur because of the high electrical field that is generated when alternating current is transmitted through a wire.

More-realistic applications of Yu and Thomas's devices will be in cables connecting generators of renewable energy, to level up power when individual generators are not producing as much energy as their neighbours — for example, when a cloud passes over a solar-energy farm. The devices might also be useful for storing the electrical energy produced by solar panels or wind-power generators<sup>4</sup>. Furthermore, coaxial cables that store energy (using either supercapacitors or coaxial batteries<sup>5,6</sup>) might help to miniaturize electronic devices by decreasing the size of the bulky batteries that are currently used. Alternatively, capacitive storage could be used to increase the lifetime of batteries in electronic equipment, and the time between charges. However, the adoption of energy-storing cables as replacements for stand-alone supercapacitors or batteries will depend on whether low-cost materials such as carbon can be used, and on the development of simple manufacturing processes.

Finally, there is a tremendous and rapidly growing interest in energy-storage devices and systems that are flexible, wearable and that can be integrated into textiles<sup>7,8</sup>. Lightweight, flexible coaxial cables could be used in knitted textiles. If the cable is too thick or



## 50 Years Ago

'Science in a state of siege' — At that same meeting I was trying to explain the work on polyelectrolytes which had started in the Weizmann Institute. I was interrupted by a woman who asked, "Polly who?" I said, 'Polly nobody' and went on to explain the polyelectrolytic phenomenon ... Briefly and over-simply polyelectrolytes are long-chain macromolecules ... which have become coiled up and can uncoil ... The homeliest example I can think of is a table jelly; you put crystals, or a gelatinous slab, in water and the polyelectrolyte molecules uncoil and expand to fill the jelly-mould. So housewives have been experimenting with polyelectrolytes for a very long time. [Prof. Richie Calder](#)  
From *Nature* 30 May 1964

## 100 Years Ago

*Sounds and Signs: a Criticism of the Alphabet with Suggestions for Reform* by Archer Wilde — The main object of this book is to advocate modifications in our present alphabet, so as to make it suitable for representing English sounds ... the suggested alphabet is portrayed; the capitals are practically identical with the small letters, but slightly more ornate. A characteristic is that no letter projects above or below the line; nor are parts of each letter thicker or thinner than others; the character is what is termed "Doric." ... In the example ... of printing in Doric capitals, the effect is to dazzle the eyes; it is not easy reading. The author is not sanguine as to the adoption of his scheme; but he opens the interesting question whether if our alphabet is to be modified, convenience is to be increased by carefully choosing the form of the letters.  
From *Nature* 28 May 1914

inflexible for knitting, it could still be embedded in textiles to provide power and transmit signals to and from sensor arrays implanted into clothes<sup>7,8</sup>. Indeed, coaxial-fibre supercapacitors for textile electronics have already been reported<sup>9</sup>, in which a core electrode 230 micrometres in diameter was made from bundles of carbon microfibres coated with multi-walled carbon nanotubes, with carbon-nanofibre paper acting as the outer electrode. All-carbon electrodes are light and stable, and could potentially be wrapped around copper

wires (including those bearing copper oxide nanowires) to form coaxial devices similar to those of Yu and Thomas. ■

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that this piRNA is required for female sex determination. Furthermore, they demonstrate that *Fem* piRNA targets and cleaves an mRNA molecule transcribed from a gene on the Z chromosome, *Masculinizer* (*Masc*), which encodes the zinc-finger protein masculinizer (*Masc*).

Kiuchi and colleagues find that, in the absence of *Fem* piRNA (in embryos lacking the W chromosome), *Masc* promotes male-specific splicing of *Bmdsx*, resulting in male development. *Fem* piRNA inhibits male development in WZ embryos by down-regulating the level of *Masc* (Fig. 1). Female-specific *Bmdsx* splicing then occurs by default, ensuring female development. Thus, the W-encoded *Fem* piRNA is the long-sought primary trigger of female development.

The detailed molecular mechanism revealed by this work may shed light on sex determination in most lepidopterans. Exceptions to the WZ system include 'primitive' moths such as the Micropterigidae and Hepialidae (which arose before the evolution of W and so lack this chromosome and have a ZZ system like their closest relatives, caddisflies) and some 'advanced' species, such as the Eri silkworm *Samia cynthia ricini*, in which the W chromosome has been lost<sup>8</sup>.

Because W chromosomes are transmitted only through females, they cannot undergo recombination — a mechanism that generates genetic variation in other chromosome pairs, and that also prevents mutations that

## DEVELOPMENTAL GENETICS

# Female silkworms have the sex factor

**Sex determination in the silkworm *Bombyx mori* has been found to depend on the presence or absence of a small RNA. This is thought to be the first example of a molecule other than a protein mediating this process. SEE LETTER P.633**

FRANTIŠEK MAREC

Over the past 80 years, a growing body of evidence<sup>1,2</sup> has suggested that, in the silkworm *Bombyx mori*, sex is determined by the presence or absence of a maternally inherited sex chromosome, known as W. But despite years of searching for a protein-coding gene on W that could be the primary trigger for development as a female, the molecular mechanism of sex determination in the silkworm has remained unknown<sup>3</sup>. On page 633 of this issue, Kiuchi *et al.*<sup>4</sup> report the discovery of a surprising, RNA-mediated pathway of sex determination in *B. mori*.

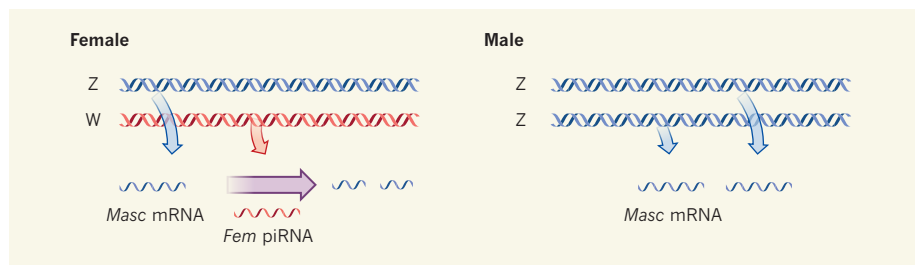
In many insects, the development of sexual characteristics involves an evolutionarily conserved mechanism: sex-specific regulation of the gene *doublesex* (ref. 5). In *B. mori*, as in the fruit fly *Drosophila melanogaster*, transcription of *doublesex* produces different forms of messenger RNA in males and females<sup>6</sup>, a process called alternative splicing. The different mRNA transcripts then turn on sex-specific gene expression, giving rise to male or female traits<sup>5</sup>. But what is the sex-determining factor that controls splicing of *Bombyx mori doublesex* (*Bmdsx*)?

In silkworms, as in most members of Lepidoptera (moths and butterflies), sex is dependent on 'WZ' sex chromosomes, in contrast to the XY system found in many other species, including mammals. In WZ systems, an embryo with one W and one Z chromosome develops as a female, and an embryo with two Z chromosomes develops as a male. The W chromosome of *B. mori* lacks protein-coding genes and consists mainly of transposons —

mobile genetic elements that move around within the genome and can thus cause mutations. The only transcripts produced from the W chromosome are PIWI-interacting RNAs (piRNAs), small RNAs that inhibit transposons in animals' gonads by interacting with PIWI proteins<sup>7</sup>.

To identify potential sex determinants on W, Kiuchi *et al.* performed in-depth sequencing of the RNA transcripts expressed in female and male *B. mori* embryos. They identified one transcript that is expressed in females at all stages of development, but never in males. This transcript is a precursor of a female-specific piRNA, which the researchers name *Fem* piRNA.

The authors report that inhibiting the expression of *Fem* piRNA in female embryos changes the splicing pattern of *Bmdsx* mRNA from the female to the male form, suggesting



**Figure 1 | Sex determination in silkworms.** In most moths and butterflies, sex is dependent on whether or not the embryo has a W chromosome — embryos with one W and one Z chromosome develop as females, whereas embryos with two Z chromosomes become male. Kiuchi *et al.*<sup>4</sup> report that a PIWI-interacting RNA (*Fem* piRNA) molecule transcribed from the W chromosome is responsible for sex determination in the silkworm *Bombyx mori*. The authors find that *Fem* piRNA cleaves *Masc* messenger RNA, which is transcribed from the Z chromosome. In ZZ embryos, expression of *Masc* promotes the expression of 'male' genes. In WZ embryos, *Fem* piRNA decreases levels of *Masc*, leading to female development by default.