extensive contextual information is unable to increase processing speed—perhaps because neuronal processing is already so optimized that there is no room for further improvement.

Could the category-specific activation reported in monkey ITC and PFC at around 100 ms correspond to the 150-ms activation seen in humans? Similarities between the monkey and human brain are difficult to establish, but those between monkey ITC and the more ventrally located human fusiform gyrus (where much of the category-related activation seems to be generated) are striking. Why is it, then, that the onset latencies differ between the two species? One possible reason is simply that the monkey brain is smaller than ours. There is not a great deal of detailed information available, but the conduction velocity of intracortical axons used to send information from V1 to V2 to V4 to ITC could be relatively slow, perhaps only 1 to 2 m/s (*22*). This means that quite a lot of time may be taken up by simply getting information from A to B—a problem that is less serious when your brain is smaller.

But the question still remains whether the category-specific activity seen in humans corresponds to categorization of the type described by Freedman *et al.* in monkeys, in which the boundaries between categories are specifically coded by single cells. The alternative is that the strong responses recorded from structures such as the fusiform gyrus in humans reflect the activity of large overlapping populations of neurons tuned to particular sets of objects, as appears to be the case in monkey ITC. The most direct test requires single-cell recording from individual neurons. Although normally this is not possible in humans, intracerebral recording in patients with severe epilepsy recently allowed progress to be made. For example, recording of individual neurons in the human medial temporal lobe revealed neuronal responses that were selective not only for faces, but also for natural scenes, houses, famous people, and animals (*23*).

These new data—regardless of whether they represent the rapid selective visual responses of ITC and PFC neurons in monkeys, the rapid category-specific signals seen in humans, or the fast behavioral reaction times seen in both species—pose a major problem for current models of visual processing. In particular, they imply that a great deal of processing can be done on the basis of a largely automatic feedforward pass through the visual system. In a sense, the fact that visual categorization is fast and robust is perhaps not so surprising. We all have the impression that as we zap from channel to channel, the moment when we categorize what the image contains is virtually instantaneous. The problem now is to understand how the brain can perform this task so quickly and efficiently with neurons that fire electrical impulses 10 million times less rapidly than the transistors in today's desktop computers.

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PERSPECTIVES: MOLECULAR METALS

Staying Neutral for a Change

Patrick Cassoux

The properties of molecular solids often resemble those of the isolated molecule, but some properties, such as conducting behavior, may be quite distinct. This type of behavior may sometimes appear counterintuitive because molecular concepts and methods are quite different from those commonly used in solid state chemistry. Nevertheless, predictions of conducting molecular compounds were made as early as 1911 (*1*). The first observation of high conductivity for a molecular compound, a perylene bromide salt, was reported by Akamatu *et al.* (*2*). The first "organic metal" down to low temperatures was characterized in 1973 (*3*, *4*) and the first molecular superconductor in 1980 (*5*). Today, several thousand molecular metals and over 100 molecular superconductors are known (*6*, *7*).

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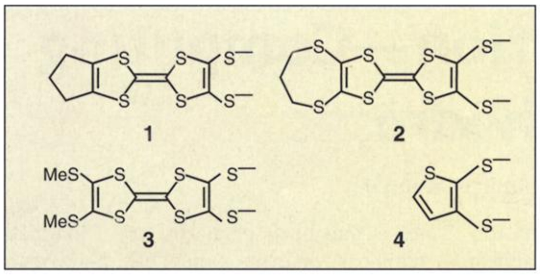


How to make neutral molecular metals. These four ligands have been used to make neutral molecular metals. **1**, tmdt^{2-}; **2**, ptdt^{2-}; **3**, $(C_{10}H_{10}S_8)^{2-}$; and **4**, α-tpdt^{2-}. The most successful attempt used **1** (*8*).

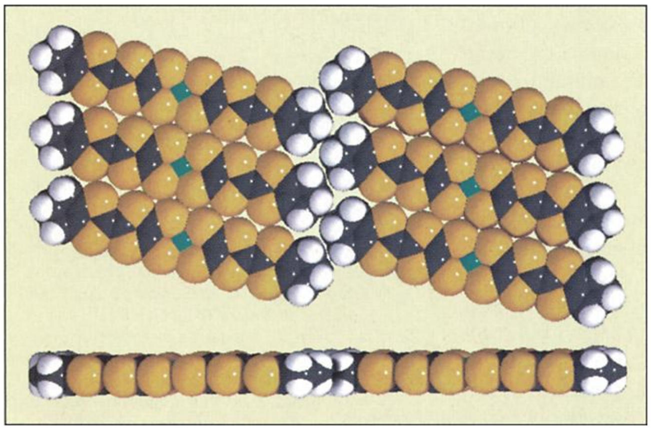
Several structural and electronic criteria have been proposed for the design of molecular metals (and possibly superconductors). In particular, the presence of formal nonintegral oxidation states either through partial charge transfer between a donor molecule and an acceptor molecule (*3*, *4*) or through partial oxidation of a donor molecule (*5*) was believed to be a prerequisite for achieving partial filling of the conduction band (a key condition for metallicity). A neutral molecular metal thus seemed impossible.

But never say never. On page 285 of this issue, Tanaka *et al.* (*8*) describe the synthesis and characterization of $[Ni(tmdt)_2]$ (see structure **1** in the first figure), the first fully characterized single-component neutral compound exhibiting metal-like conductivity behavior down to 0.6 K. The material is particularly interesting because it questions the above-mentioned notions about the requirements for molecular conductors.

The first hint for a possible metal-like behavior in a single-component neutral compound was found for $[Ni(C_{10}H_{10}S_8)_2]$ (structure **3**) (*9*). This was followed by a seminal paper by Kobayashi *et al.* (*10*), who reported the semiconducting properties of the single-component neutral $[Ni(ptdt)_2]$ compound (structure **2**). On the basis of a thorough analysis of band structure calculations, the authors daringly proposed a set of requirements for designing single-component neutral molecular metals. The proposed requirements were a small HOMO-LU-

MO (*11*) energy gap (such that the resulting bands may overlap), large three-dimensional transverse intermolecular interactions, and possibly the formation of parallel bands (*9*). These conditions are partially (*12*) fulfilled in the case of [Ni(tmdt)$_2$], as now reported in (*8*).

Tanaka *et al.* (*8*) provide full confirmation of the existence of metal-like behavior in a single-component neutral compound down to low temperatures and open new avenues to the preparation of molecular metals (and possibly superconductors). As shown in the second figure, [Ni(tmdt)$_2$] crystallizes into a closely packed structure with a perfectly planar molecular arrangement. Short S···S interatomic distances between molecules both within and between the molecular planes result in three-dimensional intermolecular interactions, as confirmed by calculations. It is this aspect of the molecular crystal that enables full metallicity.



Crystal structure of [Ni(tmdt)$_2$]. The view along the *b* axis (**top**) and a side view along the molecular long axis (**bottom**) are shown. The side view illustrates the perfect planarity of the molecular arrangement. Ni, green; S, yellow; C, gray; and H, white.

Almost simultaneously to Tanaka *et al.*'s finding, Almeida and co-workers report the strikingly high room-temperature conductivity of compacted powders of another, although not as well characterized, single-component neutral compound, [Au(α-tpdt)$_2$] (structure **4**) (*13*). Note that the three molecules studied in (*8*, *10*, *13*) are all transition metal complexes of sulfur-containing π-delocalized ligands derived from tetrathiafulvalene [a component in the first organic metal (*3*, *4*)].

There are many examples of preconceived ideas that have been contradicted by experiment. Some recent and striking examples happen to be found in the field of conducting materials. For example, until the late 1980s, the prevailing superconductivity theory was understood to predict that the superconducting critical temperature T_c of any material could not exceed 23 K or so. Today, copper oxide–based superconductors with high T_c's (claimed by some to reach room temperature) are taken for granted. It was also long thought that the presence of magnetic ions in the structure of any molecular conductor should decrease or suppress superconductivity. Yet in 1995, P. Day and coworkers reported the first molecular paramagnetic superconductor (*14*). Finally, could one have imagined just a few months ago that Schön *et al.* could turn pentacene into a superconductor by injecting this insulator with charge using a field-effect transistor (*15*)?

Yes indeed, never say never.

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11. HOMO, highest occupied molecular orbital; LUMO, lowest unoccupied molecular orbital.
12. It should be noted, however, that in [Ni(tmdt)$_2$], the HOMO and LUMO form "crossing bands." It is only because of strong transverse intermolecular interactions that sufficiently large three-dimensional electron and hole Fermi surfaces are generated.
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PERSPECTIVES: ECOLOGY

Bird Navigation—Computing Orthodromes

Rudiger Wehner

Studies of bird navigation usually follow two gold standard approaches: the relocation and release of thousands of pigeons and the tracking of their return, and the hand raising of hundreds of songbirds and the testing of their navigation capabilities in orientation cages. The data obtained from such endeavors are exciting, but the conclusions drawn are varied, often controversial, and always hypothetical, because little is known about how the avian brain computes navigational information. A favorite hypothesis is that birds primarily use a magnetic compass, or even a magnetic map of the Earth (*1*), to navigate, but so far magnetoreceptive sensory neurons have not been found in the brains of any bird species. Numerous laboratory experiments show that migratory birds use multiple sources of directional information based on magnetic, stellar, solar, and other environmental cues (*2*). Such experiments further suggest that birds must have ways to calibrate their celestial and magnetic compasses against each other (*3*), but how this is achieved as they fly vast distances on their annual journey is not known. There is good evidence that young birds are equipped with endogenous migratory programs, which tell them roughly how many days and/or nights that they must fly, and in what direction (*4*). Computational models suggest that such clock-and-compass strategies might explain the accurate "geographical knowledge" carried by avian migrants, which has been revealed by recovery of ringed birds (*5*, *6*).

Two experimental approaches could help to sort out exactly how birds navigate. The first is to record the trajectories of migrating birds with radar tracking or satellite-based telemetry. The second, complementary strategy is to look for particular combinations of real-world geographical cues in selected areas of the Earth and to relate the directional choices of migrating birds to these cues. As reported on page 300 of this issue, Alerstam and his crew have successfully combined both of these approaches.

These investigators tracked the trajectories of migrating Arctic shorebirds with

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