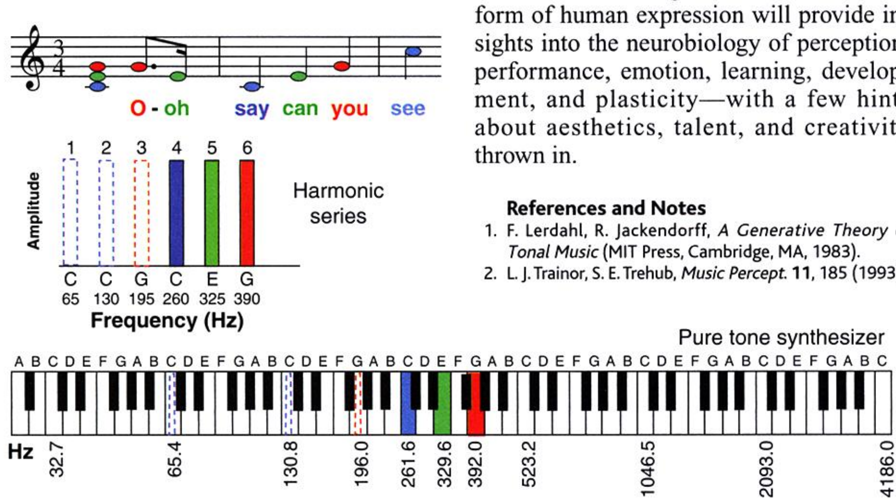
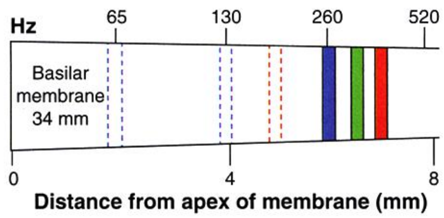
manipulate emotion is of interest not only to musicians and musicologists, but also to psychologists, movie producers, and, of course, politicians.

Ultimately, if we wish to explore the neurobiological foundations of music, we must design experiments that cross the traditional divide between science and the arts. Understanding music as a universal form of human expression will provide insights into the neurobiology of perception, performance, emotion, learning, development, and plasticity—with a few hints about aesthetics, talent, and creativity thrown in.





"The Star-Spangled Banner." The relation of the first few notes of the U.S. national anthem to the harmonic series, the keys on a piano, and the orderly mapping of different sound frequencies along the basilar membrane of the cochlea. Colors denote frequencies that are an octave apart.

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33. I thank P. Cariani, D. Hubel, M. Hauser, M. Gazzaniga, and P. Gray for helpful comments.

PERSPECTIVES: CHEMISTRY

Switched-On Nickel

Robert H. Crabtree

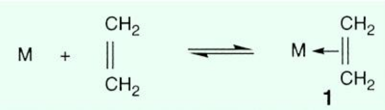
Nature usually provides chemists with mixtures of substances from which we must separate individual compounds of value. For example, olefins such as ethylene, $H_2C{=}CH_2$, are key intermediates in the petrochemical industry that often need to be separated from refinery mixtures. Sophisticated methods like chromatography can be used for small-scale separation, but industrial-scale work usually requires energy-intensive distillation steps.

Separating compounds by chemical functionality rather than boiling point is a much more attractive concept. For example, olefins can in principle be separated from a mixture by adding a suitable metal or metal complex that selectively forms a complex with the olefin (see structure **1** in the figure). This is a well-known process, but the olefin usually binds reversibly. For the concept to work for separation, the olefin has to bind irreversibly in the absorption step, and there has to be a reliable and practical way to detach the bound olefin from the metal in the release step. In addition, poisoning of the absorbent by common impurities must be avoided; many such impurities tend to bind more tightly to metals than do olefins.

On page 106 of this issue, Wang and Stiefel (*1*) introduce a new approach to the old problem of separation by providing a convenient on/off switch for ligand binding in the form of an electrochemical potential. By adding or removing one electron from a nickel complex, the complex can be switched between several oxidation states. The oxidized state binds the olefin and the reduced states release it (see the figure).

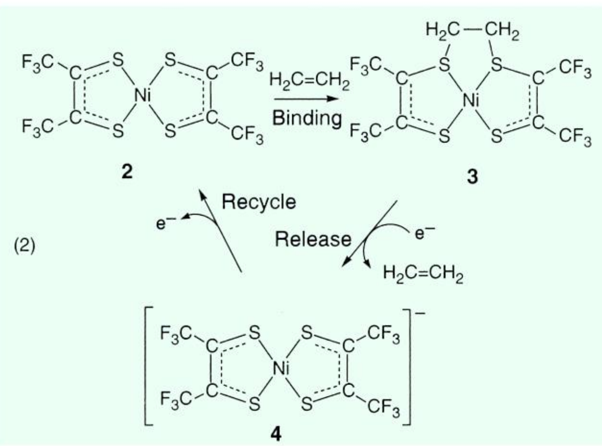
The nickel complex, a dithiolene, has long been known and has always been re-

(1)



1

(2)



Electrochemical on/off switch. Usually, olefins bind to metal complexes via the metal itself (structure **1**). The nickel complex used by Wang and Stiefel (*1*) is unusual in that when the oxidized complex (structure **2**) encounters an olefin, the olefin binds to the sulfurs (structure **3**). Poisoning by common impurities is thus avoided. The olefin is released through electrochemical reduction of the complex, resulting in structure **4**. It is then ready for another cycle of oxidation, olefin uptake, and reductive release.

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garded as exceptional even among the often bizarre menagerie of inorganic compounds (*2*). It lends itself particularly well to electrochemical oxidation and reduction because the extensive electron delocalization in the double-ring system stabilizes the different states involved. The fully reduced form of the compound, $[NiL_2]^{2-}$, can be reversibly oxidized, first to $[NiL_2]^-$ and then to neutral $[NiL_2]$. Only the oxidized form, structure **2**, binds olefins, but not in the conventional way via a direct metal-olefin bond as in structure **1**; instead, the olefin forms a bridge between the sulfurs to form the highly unusual ring structure **3**. Binding of certain olefins to $[NiL_2]$ was seen (*3*) as early as 1965, but the observation was lost and forgotten until resurrected in its new guise. This abnormal binding is important because it makes the complexation selective for olefins over such species as H_2S, CO, and even HC≡CH, common impurities in refinery mixtures that usually bind more strongly to metals than do olefins whenever a direct metal-ligand bond is present.

The olefin seems to bind with net electron transfer from the olefin to $[NiL_2]$ and so undergoes release on reduction, when an external electron is added to the metal complex. Olefin release is rapid and clean and liberates the $[NiL_2]^-$ complex, structure **4**, which can be transformed back to the reactive $[NiL_2]$ form by electrochemically removing one electron.

Why was this application discovered now and not before? The answer may lie in the unusual cross-disciplinary mind-set of the present investigators. Olefin binding is normally considered the domain of organometallic chemists who tend to use even-electron heavy-metal systems (Pt, Ag) with phosphorus-based ligands; they tend to avoid electrochemistry with its one-electron oxidation/reduction steps. Bioinorganic chemists, like Stiefel, tend to prefer light metals in sulfur ligand environments, and to expect odd-electron states, all of which are common in biology, such as in the nickel hydrogenases (*4*); electrochemical methods are also common in bioinorganic work.

This imaginative work will surely spark a search for similar on/off switches, and for ways to apply these principles to practical separations and selective chemical sensors.

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PERSPECTIVES: ASTRONOMY

Orion Sheds New Light on Star and Planet Formation

Joel Kastner

Even casual observers of the night sky in winter will easily spot Orion the Hunter with its striking alignment of three bright, bluish-white belt stars. More experienced sky gazers who have trained their small telescopes on Orion know that the middle "star" in the Hunter's Sword hanging off the belt is in fact a young star cluster shrouded in glowing nebulosity. This cluster, the Trapezium, is a set of massive, hot stars born within the last million years or so. The surrounding gas and dust that they illuminate are the raw materials from which they and many hundreds of lower-mass Trapezium cluster stars have formed. Astronomers have long hypothesized that such star-formation activity is accompanied by the generation of planets.

Imaging studies have shown that the entire Orion nebula region is a hotbed of star-formation activity (see the figure). On page 93 of this issue (*1*), Briceño *et al.* report a detailed survey of a region of Orion not searched previously for young, sunlike stars. Their results support earlier suggestions that a few million years after a parent star is formed, the stage already is set for planet formation. Furthermore, this work is one of several recent studies pointing to variability as a distinguishing characteristic of stellar youth.

To understand how interstellar gas clouds might produce solar systems like ours, astronomers have looked almost exclusively to regions that, much like the Orion Nebula, contain newly formed stars embedded in massive clouds of gas and dust. Particular attention has been paid to young stars that show evidence of ongoing planet formation in the form of circumstellar disks that are the presumed sites of protoplanets. The presence of such disks has long been inferred spectroscopically (*2*). More recently, many direct images of protoplanetary disks have been obtained by the Hubble Space Telescope and large ground-based telescopes (*3*). The direct detection of these candidate protoplanetary disks, combined with the growing number of known extrasolar planets (*4*), suggests that the formation of planets may be a common occurrence. But essential aspects of this process, such as the characteristic time scales for the different stages of planet formation, have remained controversial. Observations of a few dozen nearby, young, sunlike stars suggest that, after about 10 million years, circumstellar gas and dust disks are either cleared out by planets, incorporated into planetesimals, or otherwise dispersed (*5*, *6*). But these conclusions rest on a few spectral properties measured for a relatively small number of stars.

To develop a more statistically significant sample of young stars, Briceño *et al.* used a wide-field optical imaging system to survey a large (roughly 2° by 10°) area north of the Orion Nebula, along Orion's belt. Much of this region is devoid of the raw materials necessary for ongoing star formation. The investigators used stellar variability rather than spectral indicators of the presence of a circumstellar disk (such as strong hydrogen Balmer emission lines or strong infrared emission) to identify young stars for subsequent study by spectroscopy. Because they are far from the active star-forming Orion molecular clouds, these young stars must have formed in episodes of star formation that well predate the current swarm of activity in the Orion nebula.

Using this approach, Briceño *et al.* have isolated a population of over 150 young (<10-million-year-old) stars in the vicinity of, but displaced from, the well-studied stellar nurseries in Orion (*7*). This allows them to place much firmer constraints on the time scale for accretion from a circumstellar disk onto a young star. They observe substantial differences between the spectroscopic properties of a stellar sample with a characteristic age of about 1 million years and those of a sample with a typical age of about 10 million years. A far smaller percentage of stars in the latter sample shows evidence of accretion from circumstellar gas and dust. This suggests that, if planets are to form around these slightly older stars, then planetesimals (or perhaps even protoplanets) should be present already because the raw materials necessary for protoplanetary coagulation have been severely depleted by this time. Alternatively, most circumstellar disks may become so stable

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