the arenavirus Guanarito (and perhaps others not tested) because Guanarito did not bind to isolated α-dystroglycan.

The neuropathy of leprosy (*8*) is caused in part by invasion of peripheral nerves by *M. leprae*. In lepromatous leprosy, protective immune responses are absent and bacteria can spread freely through skin and into peripheral nerves. Spread to deeper tissues is limited because the bacteria reproduce best at temperatures of 27° to 30°C. In tuberculoid leprosy, protective immune responses are present and the disease is more circumscribed, although damage to nerves still results. The Schwann cell is an important target for bacterial invasion. In the endoneurium of peripheral nerve, Schwann cells are covered by basal lamina, composed of laminin, type IV collagen, entactin/nidogen, and heparan sulfate proteoglycans. In a previous study (*9*), Rambukkana and colleagues demonstrated that *M. leprae* could bind to the G domain of the α2 chain of laminin-2 and that a recombinant protein composed of this G domain could mediate the binding of *M. leprae* to various cell types, including Schwann cells.

In the current study (*2*), Rambukkana *et al.* have shown that α-dystroglycan is a cell receptor for the binding of G domain–coated bacteria to Schwann cells and that this binding results in aggregation of cell surface α-dystroglycan and colocalization of bacteria with these aggregates. Moreover, soluble α-dystroglycan can partially inhibit the binding of coated bacteria to the cells. Characterization of the interaction between bacteria coated with the α2 G domain and isolated α-dystroglycan showed that bacterial adherence to immobilized α-dystroglycan was inhibited by EDTA (but not by heparin) and by treatments that would alter the carbohydrate chains on α-dystroglycan. Possibly the G domain has a lectin-like activity separable from its heparin-binding activity. It is not known how *M. leprae* binds to laminin-2. We can look forward to future studies designed to define the molecular details of interactions between these viral and bacterial agents of disease and dystroglycan, the pathological consequences of these interactions, and the therapeutic potential of blocking them.

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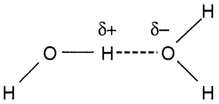
PERSPECTIVES: CHEMISTRY

A New Type of Hydrogen Bond

Robert H. Crabtree

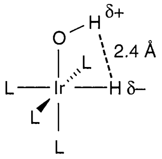
The classical hydrogen bond, known for over 50 years, plays a key role in the structure and function of biological molecules. Hydrogen bonds are responsible for the strength of materials, such as wood or a spider's web, and molecular binding, such as base pairing in DNA. Recently, however, a whole new world of hydrogen bonding has come to light, in which metals and hydrides can form unusual hydrogen bonds.

In the typical hydrogen bond, a protonic hydrogen of an XH (X = N, O) bond, the hydrogen bond donor, interacts with the basic lone pair of an electronegative atom, the hydrogen bond acceptor, as in the gas phase water dimer (see structure **1**). In the last 15 years or so, it has become clear that the π electrons of an aromatic ring can sometimes act as an H bond acceptor to form an X–H...π hydrogen bond, but this interaction tends to be weaker because π-bonding electrons are less basic than lone pairs. By extrapolation, one would expect a σ bond to be an even less effective H bond acceptor. A striking reverse of this expectation has only very recently been found (*1–3*) in the case of a Y–H σ bond as acceptor. In the resulting X–H...H–Y structure, the H...H distance, typically 1.8 Å, is much shorter than the normal H...H contact of 2.4 Å. This attractive interaction between two hydrogens has come to be called the "dihydrogen bond." Y is always an electropositive atom such as boron or a transition metal, however. This leads to a partial negative charge on the YH hydrogen atom, and the resulting H...H interaction can, therefore, be thought of as an attractive proton-hydride interaction.



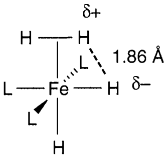
1

(δ = partial charges)



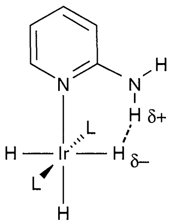
2

(L = PMe_3)



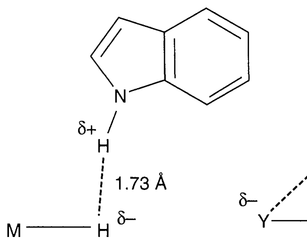
3

(L = $PEtPh_2$)



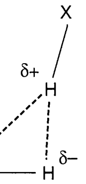
4

(L = PPh_3)



5

(M = $ReH_4(PPh_3)_3$)



6

(Y = B or tr. mtl. X = O, N)

Compounds **2** and **3** were both found by neutron diffraction in 1990 to have close H...H distances between oppositely charged hydrogen atoms (*1*). Since 1994, our group at Yale (*2*), Bob Morris' group at the University of Toronto (*3*), and many others have found that such bonding is general, as in compound **4**. X–H...H–Y structures were not found earlier probably because they tend to be unstable and readily lose H_2 to give a species with a new X–Y bond. Indeed, dihydrogen-bonded species are probably transient intermediates whenever a hydride, YH, is protonated by an acid, XH:

$$\text{X–H} + \text{H–Y} \rightarrow \text{X–H...H–Y} \rightarrow \text{X–Y} + H_2$$

Dihydrogen bonding need not be intramolecular, as in structures **2** to **4**, because the intermolecular case **5** also has a very short H...H distance (1.73 Å) (*2*). Various techniques suggest that the bond strength is generally about 4 to 6 kcal/mol, much the same as in a classical hydrogen bond of average strength (*2*).

The recent discovery (*4*) of N–H....M hydrogen-bonded structures shows that metal atoms can themselves act as H bond acceptors and suggests that there may be a direct N–H...M component to the N–H...H–M interaction. This helps explain the characteristic bent shape (see **6**) usually found for the X–H...H–Y structure but raises the question of whether X–H...H–Y structures should be considered as pre-

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dominantly X–H...σ hydrogen bonds at all. Could it be that they are really N–H...M hydrogen bonds where the true acceptor function is a nonbonding pair of electrons on the metal itself and the short H...H distance is merely a consequence of the short H...M distance?

Moving to B–H bonds as acceptor entirely removes this ambiguity because boron has no nonbonding electrons but only has the σ-bonding electrons of the B–H bond, so an N–H...σ bond is the only type of interaction that can be considered. Borane-ammonia, H_3BNH_3, attracted our attention because, although it is isoelectronic with a gas, ethane (H_3CCH_3, melting point 183°C), it is a solid with a melting point of +109°C. Just as the classical H bonding in water is thought to be responsible for elevating its melting point by nearly 100° from what it would be in the absence of H bonding, the melting point elevation in H_3BNH_3 seemed abnormally high unless dihydrogen bonding were important. Although the reported x-ray structures of H_3BNH_3 indeed indicated close H...H distances, the conformation of the N–H...H–B unit was the exact reverse (namely, structure **6**, with Y = N and X = B) of the expected conformation, (structure **6**, with Y = B and X = N). The expected conformation (**6**, with Y = B and X = N) was indeed found in a Cambridge Crystallographic Database search of many other borane amine compounds. This anomaly was sufficiently troubling that we asked Tom Koetzle and Wim Klooster of the Brookhaven National Laboratories if they could obtain a neutron-diffraction structure of H_3BNH_3 (*5*). The results unambiguously show the presence of short H...H contacts (2.02 to 2.23 Å), but the most surprising aspect of this work was the demonstration that boron and nitrogen had been misassigned in the previous x-ray work, where the distinction between B and N is less marked than in n diffraction; such a misassignment of two light elements differing by two units in atomic number was surprising. With the corrected assignment, the shortest H...H contact now indeed corresponds to the expected N–H...H–B conformation (**6** with Y = B and X = N) (*5*).

The dihydrogen bond seems to be general for interactions between hydrides YH with a hydridic hydrogen and classical hydrogen bond donor groups, such as NH or OH bonds. It has a marked structural preference and also influences physical properties. Just as nature uses the classical H bond in enzymatic catalysis, we now need to harness the dihydrogen bond to promote chemical reactivity and selectivity, for example, in chemical catalysis. This is an area that will challenge our still limited ability to design molecules to have useful and tunable catalytic properties.

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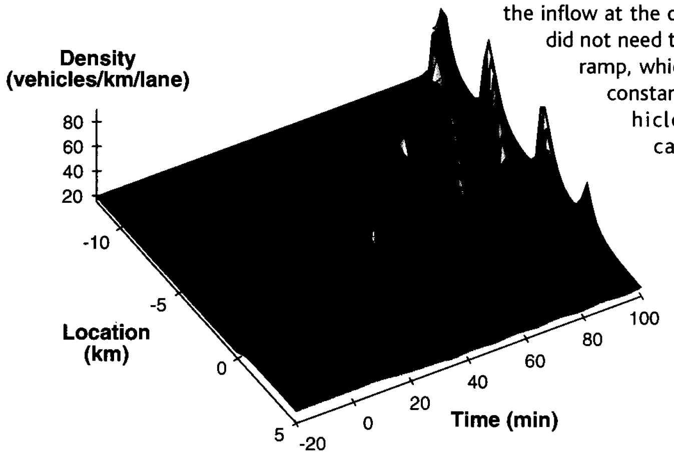
PERSPECTIVES: TRAFFIC THEORY

Jams, Waves, and Clusters

Dirk Helbing and Martin Treiber

Have you been suffering from traffic jams lately and asking yourself why freeways are not free ways anymore? Help may be on the way. There have been several recent advances in traffic theory, notably those that treat traffic like a fluid. Researchers at Seoul National University (*1*) have now offered an interpretation of a recently discovered state of congested traffic, called "synchronized" traffic (*2*). Their fluid-dynamic simulations could be a useful tool for an optimization of traffic flow on motorways.



Life in the slow lane. Formation of the recurring hump state (RH) on a freeway for the model and parameters used by Lee *et al.* (*1*). Because we used free rather than periodic boundary conditions, the inflow at the on-ramp located at 0 km did not need to be balanced by an off-ramp, which is more realistic. The constant ramp flow of 318 vehicles per hour and lane causes a higher vehicle density downstream of the ramp. Nevertheless, free flow pertains, until a short perturbation of the ramp flow occurs at time 0 min, which moves downstream in the beginning. However, with growing amplitude, the perturbation changes its propagation speed, reverses its direction, and finally induces another, bigger perturbation, when passing the ramp. This process repeats again and again, in this way generating the oscillating RH state. When passing the ramp, the perturbations continue their way upstream, until they merge with one of the humps that were born later.

When Nagel and Schreckenberg presented their cellular automaton model of traffic flow in 1992 (*3*), allowing for a more than real-time simulation of the entire road system of large cities, they probably did not anticipate the resulting flood of publications and the enthusiasm among scientists on the subject of traffic theory. By treating huge numbers of interacting vehicles similar to classical many-particle systems, physicists have recently contributed to a better understanding of traffic flow. The mathematical tools that they use, stemming mainly from statistical physics and nonlinear dynamics, have proved their interdisciplinary value many times. This includes concepts reaching from self-organized criticality and phase transitions up to the kinetic theory of gases, fluids, and granular media.

In traffic, drivers try to maximize their own advantage (that is, their velocity, safety, and comfort) within the constraints imposed by physical limitations and traffic rules. Under certain conditions, their competitive, nonlinear interactions give rise to the formation of collective patterns of motion like traffic jams. The various observed phenomena on freeways are surprisingly rich: Apart from free traffic and extended traffic jams behind bottlenecks, there are

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