

Virtue in imperfect models

Calculation from first principles is necessary in establishing the validity of a theory, but less than rigorous intermediate models of reality retain an important function.

WHEN can an explanation of a physical phenomenon be counted as complete? It is a sufficient test that the phenomenon should be calculable from some explicit set of first principles, but there is a sense in which this is also a necessary requirement of what passes as explanation. Who, after all, would take Newton's laws seriously if it were not possible to use them for calculating the properties of any classical systems, perhaps with the help of a Cray machine?

But the role of calculation in testing a theory can easily be exaggerated. There has to be enough of it, and the sources of disagreement between calculation and measurement have to be sufficiently understood, for the community of those concerned to be convinced that the theory could be a starting point for the calculation of everything. But that does not signal that everything should be calculated. There are, after all, always errors of calculation, and one of the most persuasive criteria in assessing the validity of a theory is that successive computational improvements should yield results converging towards the measurements.

So there is a continuing need for intermediate models of reality, even rules of thumb, for predicting the properties of the real world. Numerical meteorology may have made great progress in the past few years, but weather forecasters still rightly stick with much of their ancient lore about the behaviour of the atmosphere. And despite the marvellous Cray-assisted flowering of computational chemistry in the past few years, chemists are not going to forget, for example, their familiar textbook rules about the likelihood that particular substituents will turn up at one of the three accessible positions in a monosubstituted benzene ring.

It is not simply that all computations are inaccurate (like all measurements, but sometimes more so), but that they often lack what people insist on calling "heuristic value" — at least at the beginning, they do not provide the mind with a view of reality that is easily comprehended. So it is right and proper that people should be on the look-out for intermediate models of reality.

One interesting venture of this kind is an account by Christopher A. Hunter and Jeremy K. M. Sanders, from the University of Cambridge, of how the interaction between molecules with conjugated electronic systems (as in the archetype

benzene) may be accounted for (*J. Amer. chem. Soc.* **112**, 5525; 1990). Their starting point is the habit of molecules with a planar porphyrin core (as in myoglobin, haemoglobin and chlorophyll) to form face-to-face stacks, but the phenomenon arises in many other circumstances — the stacking of purine and pyrimidine bases in DNA (and the intercalation of drug molecules therein), the stacking of successive conjugated planar arrays of carbon atoms as in graphite (and, more intriguingly, the crystal structure of conjugated molecules being canvassed as molecular electronic devices) as well as in the interaction of amino acids carrying phenyl groups in folded proteins, for example.

Computational chemists are these days well able to calculate, say, the potential energy of two benzene molecules as a function of their separation and relative orientation, but Hunter and Sanders show a trace of impatience with the results. Noting that there have been some *ab initio* calculations, they nevertheless complain that these "do not explain the basic mechanisms of π - π interactions in a way that is helpful or predictive for the practical chemist". Instead, they have developed a kind of electrostatic model of the interaction between two conjugated systems that appears to work quite well.

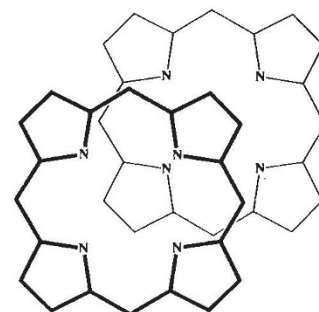
This is how the model goes. Two neighbouring carbon atoms in a conjugated system are held together by two valence bonds — one (called σ) formed by the overlap between spherically symmetrical (*s*) electron states, the other (called π) formed by interaction between atomic *p* states which, in a ring system such as benzene, have an axis of symmetry perpendicular to the plane of the molecule. The result, in benzene and other ring systems, is a two-part electron distribution concentrated along the line joining two adjacent carbon atoms (σ) and in rings tracing the outline of the ring system both above and below the plane of the molecule (π). In this simple picture, the atoms of the underlying skeleton carry positive electric charge.

So why not attempt to calculate the potential energy of two interacting conjugated ring molecules by adding together known interactions between them? Hunter and Sanders conclude that van der Waals interactions alone would lead to the maximization of overlap between the π systems in adjacent molecules, which is contradicted by observation. (In graphite,

for example, successive planes of carbon atoms are displaced by one third of the longest dimension of a six-membered carbon hexagon.)

So they represent each carbon atom in a conjugated system as a simple three-component electrostatic structure, with a central positive charge (of one unit in the simplest case) and two outlying negative charges of half a unit (for a neutral molecule) at equal distances above and below the plane. (The exact distance is derived from the measured dipole moment of benzene.) Hunter and Sanders boast that their calculations have been done with a Macintosh machine, not a Cray.

The outcome is pleasing. First, it emerges that two parallel porphyrin rings have the smallest energy when their centres are offset. (The figure shows the



calculated configuration of least energy at a separation of 3.4 Å.) Metal ions (Zn^{2+} , Mg^{2+} or $Fe^{2+/3+}$) coordinated to the four apical nitrogens of the pyrrole rings do not change the position of the energy-minimum, but affect the energy of interaction. The authors could claim breathtaking agreement between their calculation of the offset of molecules in neighbouring planes of crystalline kekulene, the conjugated planar molecule consisting of a ring of twelve benzene rings.

Emboldened by these successes, Hunter and Sanders put forward six rules which they expect will govern the stacking properties of conjugated planar molecules. It will be intriguing to see how well they work in practice. But the simple principle that emerges from their argument is that what might have been expected to be a dominant electrostatic repulsion between the σ -electron systems is more than outbalanced by the attraction between σ electrons on one molecule and the π framework of the other. It seems unlikely that that will be overturned even by the Cray battalions. **John Maddox**