

News Item

Self-Destructive Molecule Lives Longer in Prison

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AMERICAN chemists have tamed one of the wildest molecules: cyclobutadiene. The compound is so unstable that its fleeting existence can be inferred only from the fragments left after it has reacted.

Cyclobutadiene is a hydrocarbon that contains a square of four carbon atoms, each of which is attached to a hydrogen atom (see Figure 1). Donald Cram and his team at the University of California, Los Angeles, prepared the compound inside another molecule, which acts as a kind of prison, preventing cyclobutadiene from escaping while keeping out other molecules that might react chemically with it (*Angew. Chem., Int. Ed. Engl.* **30**, 1024 (1991)).

Some molecules are inherently unstable. These are the wild molecules like cyclobutadiene that theoretical chemists say are so unstable that they will instantly fall apart or react. As soon as cyclobutadiene is made, the molecule combines with itself (dimerises), or reacts with any other suitable molecule that happens to be present.

Cyclobutadiene is so unstable because it is 'anti-aromatic'. Aromaticity is an important concept in organic chemistry, originally devised to describe the special chemical stability of benzene and its derivatives. The concept has been expanded to include a whole class of organic compounds called cyclic polyenes.

These are ring-shaped molecules with a skeleton of carbon atoms connected by a series of alternating double and single bonds. Benzene, the classic example, has a ring of six carbon atoms connected by three double and single bonds, and is stable. Cyclobutadiene, on the other hand, has four carbon atoms connected by two double and two single bonds and is unstable. Why the difference?

Any molecule that contains double bonds ought to be reactive, like ethene. But when double bonds alternate with single bonds, they "delocalise". In other words, the six so-called π -electrons that form benzene's three double bonds spread out into several oddly shaped clouds above and below the flat hexagon made up of the six carbon atoms. This delocalisation stabilises the energy of the system and is what chemists mean by aromaticity.

But aromatic stabilisation does not occur to all cyclic polyenes. Using simple molecular orbital theory, the German theoretical chemist, Walter Huckel, predicted that to be aromatic, a flat, cyclic polyene had to have $[4n + 2]$ π -electrons, where n is a whole number. So, according to Huckel, a cyclic polyene containing 2, 6, 10, 14, 18... $4n + 2$ π -electrons will be aromatic. Any other number of π -electrons will not be stabilised in this way.

What about those cyclic polyenes that do not have $4n + 2$ electrons? Cyclobutadiene has only four π -electrons, so according to Huckel should be inherently unstable. Many synthetic chemists have tried to make it and failed. Then came Donald Cram with a new approach to making the molecule.

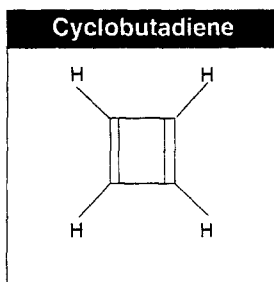


Fig. 1. Tamed at last: one of nature's wild molecules.

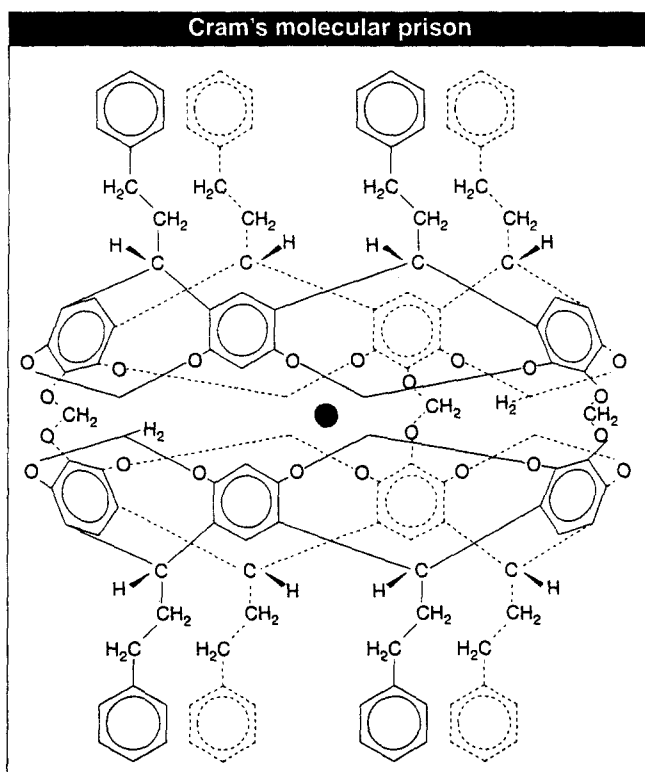


Fig. 2. Molecular prison: Donald Cram made cyclobutadiene in the cavity (•) between two bowl-shaped molecules.

Cram shared the Nobel Prize for Chemistry with Jean-Marie Lehn and Charles Pedersen for discovering a branch of organic chemistry known as 'host-guest' chemistry. Recently, Cram has become expert in building bowl-shaped molecules whose inside cavities can reversibly bind small molecules. By fitting two of these bowls together, one on top of the other, he has managed to construct a molecular prison or, in his words, a 'hemicarcerand' (see Figure 2). This binds a small molecule and will not let it escape unless the temperature is raised to give the prisoner enough energy to wriggle through the bars.

Cram's strategy was simple. He knew that when light shines onto a compound called alphapyrone, it reacts to initiate a sequence of reactions that ultimately gives cyclobutadiene. Normally, the cyclobutadiene quickly reacts with itself. So he trapped the alphapyrone in a hemicarcerand before reacting it photochemically. The cyclobutadiene survived.

Using standard spectroscopic techniques, Cram observed it spinning rapidly inside the hemicarcerand, which stabilised it from any further reaction. When the hemicarcerand-cyclobutadiene complex was heated, the cyclobutadiene escaped and promptly reacted with itself.

Cram believes that his molecular prisons will be able to tame other elusive, wild molecules for chemists to examine.