Single molecule performs multiple logic operations simultaneously

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(Left) The structure of the FG-DTE molecule, which is made of three photochromes that can switch between two different states when irradiated with light of different wavelengths. (Right) A checklist of some of the features of the all-photonic molecular logic device. Image credit: Joakim Andréasson, et al. ©2011 American Chemical Society.

(PhysOrg.com) -- While molecules have already been used to perform individual logic operations, scientists have now shown that a single molecule can perform 13 logic operations, some of them in parallel. The molecule, which consists of three chromophores, is operated by different wavelengths of light. The scientists predict that this system, with its unprecedented level of complexity, could serve as a building block of molecular computing, in which molecules rather than electrons are used for processing and manipulating information.

The scientists and engineers, Joakim Andréasson from Chalmers University of Technology in Göteborg, Sweden; Uwe Pischel from the University of Huelva, Spain; and Stephen D. Straight, Thomas A.

Moore, Ana L. Moore, and Devens Gust from Arizona State University, have published their study called "All-Photonic Multifunctional Molecular Logic Devices" in a recent issue of the *Journal of the American Chemical Society*.

"While previous examples of molecular logic systems have been able to carry out one, or a few different logic operations, this molecule can be reconfigured to perform 13 simply by changing the input or output wavelengths," Gust told *PhysOrg.com*. "In addition, it uses light for all inputs and outputs, which avoids some of the problems encountered when using chemicals as inputs."

In general, chromophores are the parts of a molecule that absorb light of specific wavelengths while transmitting other wavelengths, and are responsible for the molecule's color. When chromophores can be switched between two different states by being irradiated with light of different wavelengths, they have the ability to perform binary logic operations and effectively serve as transistors. These photoswitchable, bistable chromophores are called photochromes.

Here, the researchers used three photochromes – one dithienylethene (DTE) and two fulgmides (FG) – to build a light-responsive molecule. Each of these photochromes can exist in either an open or closed isomeric form, and can be switched back and forth between forms with light pulses of different wavelengths.

The two forms that each photochrome can take represent the two states that serve as the basis for performing binary logic operations. Various combinations of the three photochromes in different isomeric forms can be used to perform binary arithmetic, such as addition and subtraction. Although previous molecular-based systems have performed binary arithmetic, the FG-DTE molecule is the first that can perform these operations using only two inputs: light with wavelengths of 302 nm and 397 nm. Also, all three photochromes can be reset by green light irradiation (460-590 nm). These features allow the molecule to perform addition and subtraction in parallel, simply by having light convert the photochromes to different isomeric forms.

“All of these 13 logic operations share the same initial state, that is, the molecule is always ‘reset’ to one and the same state by the use of green light, irrespective of which logic function is to be performed,” said Andréasson. “This is another unique feature of our molecule.”

The researchers also demonstrated that the FG-DTE molecule can perform non-arithmetic functions. For example, as a digital multiplexer, the molecule can act as a mimic of a mechanical rotary switch to connect any one of several inputs to an output. As a demultiplexer, the molecule can separate two signals that have been multiplexed into one output.

Further, the FG-DTE molecule can perform sequential logic functions, in which inputs must be applied in the correct order, such as for a keypad lock. The molecule can also operate as a transfer gate by transferring the state of an input to that of an output, which is useful for complicated computational operations. The researchers also demonstrated that the molecule can act as an encoder and decoder, by compressing digital information for transmission or storage, and then recovering the information in its original form.

While each of these individual logic operations has previously been performed by molecular systems, the FG-DTE molecule is the first to unite them all in a single molecular platform. Transistors and other more traditional logic devices do not have the same functional flexibility, which the researchers attribute to the chromophores' ability to respond differently to different wavelengths of light and to influence each other's properties.

As for applications, the researchers note that it's unlikely that such molecular devices will soon replace electronic computers, but they could have applications in nanotechnology and biomedicine, such as for data storage, labeling and tracking micro-objects, and programmed drug release.

"In the near term, molecular logic devices will complement, rather than compete with, electronic devices," Gust said. "In principle, molecular computing could be implemented with extremely small switch sizes, since the operational units are molecules. Photonically operated molecular devices such as the one we describe can also be easily reconfigured to perform a variety of different logic functions, can operate at high speeds, and can be arrayed in three dimensions, rather than the planar arrangements usually found in electronics.

"Molecular logic devices can be employed where electronic ones cannot," he added. "For example, they can be used to label and track nanoparticles and nanoscale components of biological organisms. On the other hand, most photochromes currently are not sufficiently stable to stand up to the large number of cycles required for useful full-scale computing. In addition, complex computing will require convenient ways for nanoscale logic devices to communicate with one another."

"In addition, the application of molecular logic in biological systems, such as the human body, is still relatively unexplored, although molecular systems are better suited for this purpose compared to electronic devices," said Andréasson.

In the future, the researchers plan to address some of the biggest challenges facing molecular logic, such as the efficient wiring (concatenation) of logic switches.

"One of the major challenges of molecular logic is concatenation of logic operations," Gust said. "In electronics, this can be done simply by wiring the output of one element to the input of the next. We need to find ways of achieving similar results in molecules."

More information: Joakim Andréasson, et al. "All-Photonic Multifunctional Molecular Logic Devices." *Journal of the American Chemical Society*. DOI:10.1021/ja203456h