Focus: Single Molecule Microphone

Published September 26, 2014 | Physics **7**, 98 (2014) | DOI: 10.1103/Physics.7.98

A single molecule can work as a vibration sensor that can detect displacements nearly as small as a proton.

Single Molecule as a Local Acoustic Detector for Mechanical Oscillators
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Phys. Rev. Lett. **113**, 135505 (2014)
Published September 26, 2014

A single molecule can act as a sensitive microphone, a research team reports. They used shifts in the optical spectrum of the molecule caused by vibrations in the surrounding matrix to measure the frequency and amplitude of the acoustic disturbance. The method might be used to develop an ultrasensitive acoustic microscope for monitoring tiny movements in chemical or nanotechnological systems.

The detection of vibrations and motions at very small scales is needed for the emerging field of nanomechanics, which studies mechanical properties of nanoscale systems. A small-motion sensor could lead to highly sensitive techniques for measuring quantum effects in systems such as tiny vibrating cantilevers.

+Enlarge image

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Good vibrations. A single molecule embedded in a crystalline matrix acts like a tiny microphone, revealing vibration amplitudes as small as 10 femtometers.

To pick up very small displacements or mechanical oscillations, a single molecule could act as the detector, according to a recent proposal by Fabio Pistolesi of the University of Bordeaux in France and his colleagues [1]. Their idea was that the electronic states of a “guest” molecule embedded in a “host” matrix are influenced by the matrix. If the host molecules get closer, due to some mechanical deformation of the matrix, for example, then interactions between the electron clouds of the guest and host slightly alter the guest’s electronic energy levels. This shift will register as a change in the precise frequency of light emitted as fluorescence from the guest molecule when an electron makes a transition from an excited state to the ground state.

To see that shift, the energy of the transition needs to be very sharply defined. It must not be blurred too much by molecular motions in the host molecules, so the experiments require very low temperatures. Michel Orrit of the University of Leiden in the Netherlands and his co-workers have now found a system satisfying these requirements, which has allowed them to put the French team’s proposal into practice.

The Leiden group used the organic molecule dibenzoterrylene (DBT) as the detector, and they mixed it into a host crystal of anthracene (Ac) at low enough concentration that each DBT molecule was isolated from the others. The host crystal, a few hundred micrometers across, was glued onto a “tuning fork” made of quartz, which could vibrate under electronic control. These vibrations were expected to stretch and compress the Ac lattice periodically, causing periodic variations in the local environment of each DBT molecule and thus also in its electronic transition frequency. As a result, the team expected the intensity of the fluorescence emission excited by a laser to rise and fall with the same frequency as the tuning fork’s vibration.

Each DBT molecule was in a slightly different environment from the others, due to Ac crystal imperfections, so the team could tune the laser frequency to stimulate fluorescence from just one molecule at a time. The researchers turned on the vibration and measured the emission from one molecule, photon by photon, over a period of about a second. When they converted these data into a plot of intensity versus frequency, a peak at the tuning fork’s vibration frequency showed that the single molecule could indeed detect the periodic distortions in the matrix.

The vibrations compressed and extended the entire crystal by a few tenths of a nanometer, which means that the local deformations detected by the molecule were just 10^{-14} m, a few times the diameter of a proton. Orrit says that adapting the technique to detect acoustic signals in arbitrary configurations would be possible but challenging, involving calibrations of the system’s responses in all three dimensions.

“The authors have realized the main aspects of our proposal,” says Pistolesi. Although Orrit admits that their detector is just a prototype, he thinks it might ultimately assist experiments that look for quantum effects in tiny vibrating systems, probing the possible size limits of quantum behavior. Observing such quantum effects “is clearly one of the most exciting goals,” says Pistolesi. He says an “acoustic microscope” might be possible in the future, but the need for ultralow temperatures might prevent the probing of live cells.

This research is published in Physical Review Letters.

–Philip Ball

Philip Ball is a freelance science writer in London and author of *Curiosity: How Science Became Interested in Everything* (2012).

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ISSN 1943-2879.