

Acoustic resonances of biological nanoparticles

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Small particles display vibrational resonances that correspond to changes in their size and shape. These modes were first observed in Raman scattering measurements in the 1980s and later in transient absorption experiments.^{1,2} For spherical particles, the resonances can be described by their angular momentum and mode number, and their frequencies are proportional to the speed of sound of the material (for breathing modes, it is the longitudinal speed of sound that is important) divided by the dimensions: $\nu \propto c_l/R$.^{1,2} Early experiments on ensemble samples established how the frequencies depended on the shape and material properties of the particles, and how the modes were excited and detected in optical experiments. The vast majority of the experiments were performed on metal nanoparticles, as the plasmon resonances of metal particles are sensitive to dimensions and give large signals in transient absorption experiments. Interestingly, the frequencies of the resonances follow the predictions of continuum mechanics calculations even down to very small sizes.^{3,4}

This field was revolutionized by the development of techniques that allow ultrafast transient absorption experiments to be performed on single particles.^{5,6} This immediately enabled studies of the lifetimes of the vibrational modes and how they depend on the environment,⁷ although this can sometimes be done for samples with extremely narrow size distributions.⁸ Single-particle experiments also revealed new effects such as vibrational coupling in dimers and aggregates^{9,10} and modes that correspond to the motion of the particle relative to the substrate.¹¹ A major challenge in single-particle transient absorption experiments is sensitivity, single nano-objects do not absorb very strongly, and considerable care and effort are needed to detect their transient absorption signals. For this reason, single-particle experiments are mostly conducted on metal nanoparticles, as they are extremely strong absorbers and can usually withstand the high powers present when an ultrafast laser is focused in an optical microscope.

In their recent paper in *Proc. Natl. Acad. Sci.*, Zhang et al.¹² reported measurements of the vibrational modes of single virus particles.¹² They showed that virus particles with sizes in the 100-nm range can be detected at high signal-to-noise ratios and display acoustic resonances with frequencies between 2 and 20 GHz. The low-frequency, few-GHz modes were assigned to the motion of the particle relative to the substrate, which is mediated by the virus envelope proteins, and the higher-frequency resonances are breathing and deformational vibrations of the virus. The spectra evolve in time, with different particles showing different dynamics. Tracking the frequencies and widths of the resonances generates information about the disassembly of viruses.¹² This is an amazing result, given that these materials are such weak absorbers. These experiments were made possible by advances in how transient absorption measurements are performed in microscopy measurements. Specifically, the authors collected the transient absorption traces using an asynchronous optical sampling system, combined with a balanced optical detector with passive electronic filters and a high-speed amplifier for signal conditioning.¹²

The ability to study the mechanical properties of viruses over time opens up many exciting possibilities in biophysics. One of the most obvious is that the measured frequencies could be used to determine size, which potentially allows unknown virus particles to be identified. The sensitivity of the frequencies and linewidths of the resonances to the state of the virus and its environment can also provide new information about the changes that occur during the natural viral lifecycle. The advances in instrumentation described in the paper are also certain to inspire workers in other fields of research. Transient absorption microscopy measurements provide useful information about a variety of processes, ranging from charge carrier trapping and exciton diffusion in semiconductors to the motion of polaritons.¹³ Being able to quickly record traces with high sensitivity is attractive for many of these applications.

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Gregory V. Hartland received his PhD from UCLA in 1991, and performed postdoctoral studies at the University of Pennsylvania from 1991 to 1994 before joining the Department of Chemistry and Biochemistry at the University of Notre Dame. His research interests are in the development and application of novel spectroscopic techniques to study energy relaxation processes in single nanostructures.

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