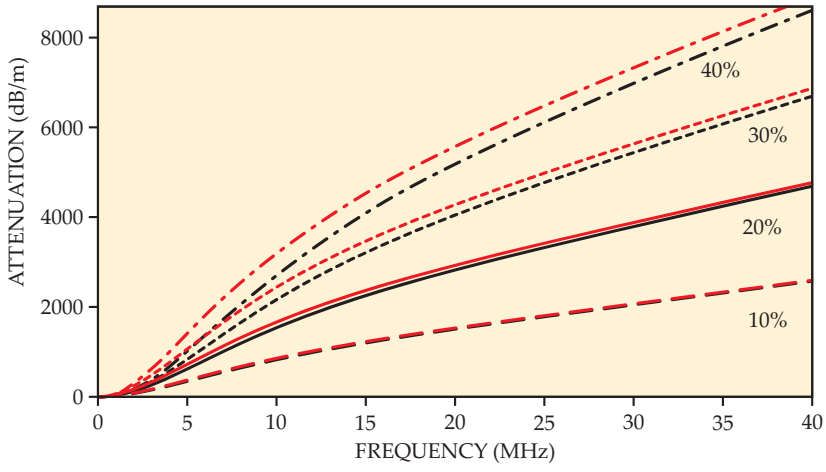
model for a long time. "However," she says, "we didn't have the mathematical tools to develop a better alternative."

Luppé learned about the problem at a series of meetings between British and French researchers, and she decided to take it on. For a general system of spherical scatterers in a background medium (not necessarily liquid droplets dispersed in a liquid), she derived an expression for an acoustic wave's effective wavenumber, a complex quantity whose real and imaginary parts are related to the wave's speed and attenuation, respectively. Her formula expressed the effective wavenumber in terms of an infinite set of transition factors that describe the scattering of waves off a single particle: Each transition factor relates one of the possible incident wave modes (compressional, thermal, or shear) to one term in the multipole expansion of one mode of the outgoing wave.

Pinfield recognized that for the emulsions she was interested in, only a few of the terms in Luppé's formula were important. First, because the liquids in an emulsion are usually close in density, multimode scattering involving shear waves could be neglected. Second, because ultrasound wavelengths are much larger than the emulsified droplets, all multipole terms higher than first order could be assumed to be zero. Third, because the processes that convert compressional waves to thermal waves and thermal to compressional operate isotropically, in those expansions only the zero-order terms are significant.



Attenuation of ultrasound waves in emulsions of 0.2-μm bromohexadecane droplets in water at four different concentrations, as predicted by the conventional scattering model (red) and a new model (black) that accounts for the scattering of thermal waves. (Adapted from ref. 3.)

The resulting expression for the acoustic attenuation is still extremely complicated, so there's no simple way to define the regime in which thermal waves need to be considered. Pinfield ran the numbers for some sample systems, including 0.2-μm droplets of bromohexadecane, a viscous oily liquid, in water. As shown in the figure, for a 10% volume fraction of bromohexadecane, the predictions of the conventional model and Pinfield's new model are similar. At higher concentrations, the difference between the two models becomes progressively larger. In those systems, using the conventional model to interpret ultrasound measurements yields, as Pinfield puts it, "complete nonsense."

Pinfield plans to conduct a thorough experimental test of her model and then to turn her attention to suspensions, or dispersions of solid particles in a liquid. Because of the density contrast between suspensions' solid and liquid components, shear waves are an important scattering mode, and the conventional model is known to perform even more poorly, with large deviations from experiment even at 10% volume fraction of particles.

Johanna Miller

References

1. P. S. Epstein, R. R. Carhart, *J. Acoust. Soc. Am.* **25**, 553 (1953); J. R. Allegra, S. A. Hawley, *J. Acoust. Soc. Am.* **51**, 1545 (1972); P. Lloyd, M. V. Berry, *Proc. Phys. Soc. London* **91**, 678 (1967).
2. F. Luppé, J.-M. Conoir, A. N. Norris, *J. Acoust. Soc. Am.* **131**, 1113 (2012).
3. V. J. Pinfield, *J. Acoust. Soc. Am.* **136**, 3008 (2014).

physics update

These items, with supplementary material, first appeared at http://www.physicstoday.org.

Rosetta's comet is rich in deuterium. Planetary scientists have long suspected that comets and asteroids delivered water and organic compounds to Earth during an epoch known as the Late Heavy Bombardment, hundreds of millions of years after the planet formed. But the cometary contributions and their provenance are under debate. Comparing the deuterium-to-hydrogen ratio (D/H) in seawater to that found in different populations of comets is a reliable way to distinguish among the possibilities. In the dozen or so orbiting comets probed to date, observed D/H ratios are thought to represent the local values where and when the comets' building blocks condensed. The latest isotopic measurement comes from the European Space Agency's *Rosetta* spacecraft, which is now orbiting the 4-km-wide comet 67P/Churyumov–Gerasimenko shown here. Using *Rosetta*'s mass spectrometer, Kathrin Altwegg of the University of Bern in Switzerland and her colleagues measured the D/H ratio of the comet's tenuous atmosphere and found it to be three times Earth's. The high value is a strike against the theory that Kuiper belt comets delivered Earth's water, which had been strengthened three years ago when the *Herschel* space telescope spotted a comet (103P/Hartley 2) whose D/H ratio matched Earth's. Like Hartley 2, comet Churyumov–Gerasimenko is thought to have originated in the Kuiper belt, just beyond Neptune's orbit. Altwegg and colleagues speculate that the inconsistent values might reflect diverse origins, despite the comets now being part of the same family. The new measurement points to chondritic asteroids, whose D/H ratios are much more consistently Earthlike, as the more likely source of our oceans. (K. Altwegg et al., *Science*, in press.) —RMW

Quantum security for your credit card. Among the many unusual features that distinguish quantum mechanics from classical mechanics is the "no-cloning" theorem: It is impossible to perfectly replicate an unknown quantum state (see the Quick Study by Bill Wootters and Wojciech Zurek, PHYSICS TODAY, February 2009, page 76). Quantum cryptography aims to exploit that property in order to keep communi-