OBITUARY

Robert Edmund Apfel (1943–2002)

"...An eye to each shore"
'By Water', Robert E. Apfel

Robert E. Apfel penned this line to evoke the all-too-human ambivalence with which we face the journey from birth to death; it is, in retrospect, a fitting metaphor for the Renaissance man that he was, his vision always able to encompass more than narrow research goals. Of his many talents, we celebrate here his broad contributions to materials science.

Bob first developed his interest in acoustics at Tufts University, from which he graduated in 1964. For his thesis project, he combined his love of music with science by studying the acoustics of an auditorium. In the process, Bob inadvertently sacrificed his left ear's ability to respond to certain frequencies as a result of using clapboards to study the auditorium's abominable acoustics. It was then that he attracted the attention of Ted Hunt, at Harvard, who remarked, "Here was this undergraduate from Tufts trying to scrounge equipment from my lab to do an acoustics experiment — I figured with those kinds of skills, he'd be a great graduate student!"

During his graduate work at Harvard for Hunt, Apfel displayed remarkable ingenuity in devising a way to measure the intrinsic tensile strength of liquids — their strength when free from impurities and from the effects of container walls. To accomplish this, he produced tiny droplets of filtered liquid that were immobilized or 'levitated' in an inert host liquid by acoustic radiation pressure, then tested their strength by using acoustic waves to place the heated samples under negative pressure. These experiments first demonstrated that the tensile strength predicted by homogeneous nucleation theory could be achieved in real liquids.

Later, at Yale University, Apfel explored other problems in nucleation. Along the way, he developed a radiation dosimeter based on small superheated droplets supported in a gel, patented in 1979 as a nuclear particle detector. The dosimeter is particularly sensitive to neutrons and also useful as a neutron spectrometer. During this time Apfel also made significant contributions to the theory of heterogeneous nucleation of bubbles by impurities and the theory of radiation-induced cavitation. He discovered that medical ultrasound machines could produce inertial cavitation — short-lived bubbles or vapour pockets whose collapse may damage tissue. This work led to new Federal Drug Authority safety standards for diagnostic ultrasound imaging.

Apfel remained at Yale for the rest of his life. As a consequence of his interest in quantifying material properties with acoustics, Apfel began to consider mixtures of liquids and biological materials. Beginning with oils extracted from the porpoise, he

PHYSICIST, ACOUSTICIAN, MUSICIAN AND SCHOLAR.

evaluated the density, sound speed and compressibility of mixtures of organic and non-organic oils and waxes. He came up with a technique for inferring the water, protein and fat content of fine emulsions from data on density, sound speed and the acoustic nonlinearity parameter. Accurate data on the nonlinearity parameter for pure materials and their mixtures were few, so Apfel and his students devised improved measurement methods and expanded the precision of published values. Such information can be adapted to the characterization of human tissues.

Once he had embarked on the path of biological material characterization, Apfel and his students thoroughly investigated acoustic scattering from (and even acoustophoresis of) red blood cells. In one clever study, Apfel acoustically levitated suspensions of red blood cells. By comparing the model equations with the experimental results, he was able to distinguish damaged cells from healthy cells simply on the basis of their mechanical properties.

One of Apfel's abiding interests was the behaviour of liquid surfaces. He again used acoustic levitation to achieve a contact-free means of both positioning and dynamically deforming spheroidal liquid drops. By observing the drop's oscillation frequency and damping, Apfel was able to determine how contamination with surfactants affected the dynamics and elasticity of the liquid surface.

When the effects of gravity proved problematic in exploring these relatively weak surface forces, he teamed up with his first PhD student, Eugene Trinh, then at NASA's Jet Propulsion Laboratory. Together they devised liquid-drop experiments in microgravity, which Trinh himself performed aboard the Space Shuttle. These unique experiments were able to quantify the competition between surface shear and surface dilatational motion in controlling dissipation in the presence of surfactants.

Before his untimely death on August 1 this year, Robert Apfel was exploring the possibility of new microgravity experiments involving his rapid decompression technique for producing lightweight polymeric and metallic foams. In this process, volatile droplets are heated under pressure within a molten material. When the pressure is rapidly released, the droplets boil, followed by supercooling of the melt and the creation of a solid, foam structure. Apfel hoped that microgravity conditions would further understanding of the droplet nucleation and growth mechanisms.

Bob's professional talents have been recognized many times. In 1971, he received the A.B. Wood Medal from the Institute of Physics for his work on the properties of liquids. His contributions to the Acoustical Society of America (ASA) included terms as vice-president in 1991–92 and as president in 1994–95. This summer, he was awarded the ASA's highest honour, the Gold Medal "for fundamental contributions to physical acoustics and biomedical ultrasound and for innovative leadership in electronic publishing" — recognition, in part, of his contribution to the creation of the Society's first fully electronic journal.

Bob's creativity and leadership was not confined to science. He found the time and inspiration to write poetry, books on creativity and a screenplay. At Yale he gave lectures to architecture students, and wrote a primer on building acoustics called *Deaf Architects and Blind Acousticians*. Bob's love of music endured a lifetime and he was an amateur concert baritone, encouraging fellow scientists to sing along during social events at ASA meetings.

Ted Hunt once wrote that Bob possessed "... a subtle trait that I can only describe as scientific zing." It was this 'zing' that attracted and inspired nearly 50 graduate students and postdocs to do their best work for him, and it is the trait for which he is most fondly remembered by his colleagues.

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