Thermoacoustic Boundary Layers Near the Critical Point

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We modeled and measured the effects of thermoacoustic boundary layers on the behavior of 6 resonance modes of an acoustic resonator filled with xenon near its critical temperature T_c. The data were taken on the critical isochore ($\rho = \rho_c$) as the temperature was reduced toward T_c. Our data for resonance frequencies and quality factors (Q) show that, as the critical point is approached, the dissipation in the boundary layers at first appears to diverge, then levels off, and finally decreases slightly very close to T_c. These observations are in agreement with an acoustic model that includes heat transport between the xenon and the resonator wall.

The model predicts that the fractional acoustic energy lost per cycle due to thermal conduction at the wall of an acoustic resonator is given by

$$Q_T^{-1} = (\gamma_x - 1)\delta_x \, \Phi[\Lambda/(\Lambda+1)]$$

expressed in terms of the heat capacity ratio for xenon γ_x, the thermal penetration length in xenon δ_x, a mode and geometry-dependent constant Φ, and a dimensionless parameter $\Lambda = [(\lambda\rho C_p)_w / (\lambda\rho C_p)_x]^{1/2}$. (The subscripts x and w refer to the properties of the xenon and the wall, respectively.) The fraction $1/(\Lambda+1)$ of the dissipation occurs in the wall and $\Lambda/(\Lambda+1)$ occurs in the xenon. Well above T_c, Λ is 100 or more so the dissipation occurs primarily in the xenon, and the usual expression for thermal dissipation in a gas-filled resonator is obtained. As T decreases toward T_c, Λ decreases and Q_T^{-1} increases due to the strong dependence of xenonís properties on the reduced temperature $t \equiv (T-T_c)/T_c$. When $\Lambda = 1$, 50% of the dissipation occurs in the wall where it is not dependent on t. As t is reduced further, the dissipation is observed to level off since most of the dissipation occurs in the wall. When $\Lambda << 1$ very close to T_c, Q_T^{-1} is proportional to $t^{3\alpha/4}$ ($\alpha = 0.11$) which decreases as t approaches zero. Both the temperature where $\Lambda = 1$ and the maximum dissipation are dependent on the properties of the wall.