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DOUBLE SOUND IN DISPARATE-MASS GAS MIXTURES

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Theoretical studies have been carried out of sound propagation in gas mixtures of very heavy with very light molecules, in particular in xenon-helium mixtures (molecular weight ratio 131.3/4). It has been shown[1] that at frequencies of the order of ω_Δ=110 MHz/atm, the xenon and helium can have separate and possibly different temperatures. The theory adequate to describe such situations has been developed by Goebel, Harris and Johnson[1], among others. This theory has been applied to the calculation of sound absorption and dispersion by Huck and Johnson[2]. Predictions for forcing frequencies of the order of ω_Δ are particularly interesting, because such frequencies are low enough for the gas to behave like a continuum, but high enough that deviations from classical behaviour are expected because of the possibility of separate species temperatures.

The predictions of Huck and Johnson[2] contained several unexpected results. The most striking of these is that, for frequencies higher than $\sim$ 70 MHz/atm, xenon-helium mixtures within a range of compositions should be able to support two different sound waves, a slow wave and a fast one. Further study[3] has indicated that these two waves correspond to different physical effects: the slow wave is analogous to an ordinary sound wave propagating in the xenon alone, while the fast wave seems to be a "dusty gas" disturbance carried by the helium, the xenon molecules acting primarily as randomly-distributed inert scattering centres.

The second unexpected result concerns the absorption and dispersion predicted by classical theory[4]. Even classically, double sound propagation is predicted to occur in xenon-helium mixtures, although the physical nature of the fast and slow waves is less apparent. The classical calculations and the two-temperature ones predict a very similar frequency dependence of the double-sound effect, but a very different dependence on the composition of the mixtures.

Predictions to date have been obtained assuming a simple intermolecular potential, proportional to the (-4) power of the intermolecular separation (Maxwell potential). A more realistic calculation might be expected to predict somewhat different values for the frequency and composition dependence of the effect, but not to obscure the difference between the classical and two-temperature predictions. Specific experimental input was the pure-gas viscosities for xenon and helium, and the coefficient of relative diffusion[4].

Specific predictions include the following, in xenon-helium at S.T.P.:

I. Double sound is predicted to be possible at frequencies higher than a critical frequency $\omega_c \gtrsim 73$ MHz/atm, corresponding to a rarefaction parameter $r \gtrsim 10.5$ (classical prediction: $\omega_c \gtrsim 84$ MHz/atm).

II. For frequencies higher than ω_c, double sound is predicted to be observable for mixtures with a helium mole-fraction x in the neighbourhood of a critical composition x_c, where $0.460 < x < 0.465$ (classical prediction: $0.225 < x_c < 0.250$).

III. The absorptions of fast and slow wave are typically high, but comparable for x near x_c.

IV. For small $x \lesssim 0.3$, say, the slow wave only should be observed, if $\omega > \omega_c$. For large $x \gtrsim 0.8$, the fast wave only should be observed.

V. The speed of the slow wave should be slightly higher than the equilibrium sound speed in pure xenon at the xenon partial pressure, with a value relatively independent of frequency.

To the best of our knowledge, double sound propagation in neutral gases has not previously been predicted or observed. It is thus of some interest to test these predictions by experiment. It seems likely that, should this phenomenon exist, its observable effects would depend upon the details of the experiment in question. Precise, experiment-related predictions have not yet been obtained. However, almost any measurement of dispersion in xenon-helium in the double-sound regime should show noticeable traces of the presence of two competing sound modes.

Experiments have begun at Surrey to investigate absorption and dispersion in xenon-helium mixtures. Short bursts of a known frequency of ultrasound are transmitted through the test gas to a receiver, while the path length in the gas is slowly increased. The velocity is determined by measuring the difference in path length required to change the phase of the received signal by 2π; the attenuation is found by measuring the received signal strength as a function of path length.

The apparatus is basically that used by Blacker[5], and consists of a stainless steel test chamber about 700 mm long and 54 mm in diameter set into a longitudinal tube furnace. Since the apparatus was designed to operate up to 1000°K, the two ultrasonic transducers (PZT-5) are mounted on buffer rods of synthetic quartz, which are used to transmit the sound energy into and out of the test chamber. The buffer rods are held in alignment by suitable rigid supports, decoupled from small movements of the test chamber by stainless steel bellows.

The output of a high-stability frequency synthesizer is gated at a repetition frequency of between 10 and 100 Hz, to produce tone bursts of 13 cycles of 1.02 MHz. These bursts are amplified and applied to the transmitting transducer. This transducer, with its buffer rod, is slowly moved away from the receiving transducer and buffer rod during measurement, by means of a motor-driven micrometer screw. A linear displacement transducer is used to monitor the movement of the transmitting transducer.

The received signal, after suitable amplification, filtering, and time gating, is applied to a phase-sensitive detector, where it is demodulated with reference to the original 1.02 MHz tone. The amplitude of the envelope of the received tone burst produced by this process is $A \cos\phi$, where A is the amplitude of the received tone burst, and ϕ is the phase difference between this received signal and the reference signal. The detected envelope is amplified, and sampled by a boxcar integrator, which is basically a sample and hold technique. A suitably designed triggering system[6] ensures that the time of sampling always occurs at the same point in the received signal, even though the path length in the test gas is being increased (thus increasing the delay in the reception of the burst).

The output of the boxcar integrator should vary with transducer separation as

$$A = A_o\, e^{-\alpha d} \cos(2\pi d/\lambda + \theta).$$

The envelope of this expression is characterised by $\exp(-\alpha d)$, thus yielding a coefficient of attenuation, and the sinusoidal variation by λ, the wavelength of ultrasound in the test gas.

Experiments on xenon-helium mixtures, using these techniques, are under way at present, and it is hoped that preliminary results can be presented.

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