

**Hayden and Lamont Reply:** We have now carried out extensive dissociative experiments of  $H_2$  and  $D_2$  on Cu(110) using pure and seeded beams together with a hot-nozzle source.<sup>1</sup> This has extended the original antiseeding experiment using  $H_2$ -He mixtures<sup>2</sup> to both isotopes seeded in Ne. The results confirm our original result that  $H_2(v=1)$  dominates sticking at the lowest translational energies, and the translational onset for  $H_2(v=1)$  is 130 meV. The seeded-curve onset, however, is not as sharp<sup>1</sup> as originally reported<sup>2</sup> and indeed we do conclude that there is some small contribution at higher translational energies to the sticking by  $H_2(v=0)$ . Our results for  $D_2$  demonstrate an isotope effect in the pure-beam experiment, and the seeded experiment allows us to deduce a translation energy onset for  $D_2(v=2)$  of approximately 60 meV. This result together with the  $H_2(v=1)$  onset confirms<sup>3</sup> an approximately 60% conversion of vibrational energy at the barrier, yielding an energy for the barrier of 600 meV. This allows us to estimate the translational onset for  $H_2(v=0)$  as 440 meV: Since the ground-state molecule is the dominant species even in the heated-nozzle beams,<sup>1,2,4</sup> some sticking contribution will indeed occur at the higher translational energies.<sup>2,4</sup> Nevertheless, the experiments demonstrate clearly<sup>1,2</sup> the importance of vibrational energy in the sticking of hydrogen on copper, the contribution of  $H_2(v=1)$  to sticking in hot-nozzle experiments, and confirm the existence of a relatively high barrier to dissociation<sup>5</sup> significantly in the exit channel.<sup>6</sup> Indeed, the values we obtain<sup>1</sup> for  $H_2(v=n)$  and  $D_2(v=n)$  are in good agreement with those predicted in the classical trajectory calculations of Harris<sup>6(a)</sup> using a barrier of 720 meV. A similar barrier height was used (700 meV)<sup>6(d)</sup> to account for the vibrational distributions of the desorbing molecules in the permeation experiment.<sup>7(d)</sup>

We also point out that there are clearly differences in the dissociative barrier on the different crystal faces of copper,<sup>4,7</sup> and both the barrier itself and the vibrational-translational coupling constant may be different. In addition, our angular-dependence measurements<sup>2,8</sup> indicate that the effectiveness of vibrational energy in accessing the dissociative barrier appears to be dependent on the incident angle, at least near the translational on-

set for the vibrational quantum state involved.<sup>1</sup> This is in addition to the effect of angle in determining the normal translational-energy requirement.<sup>2</sup> Comparison of results from different faces, and detailed-balance arguments involving angular distributions and translational velocities of desorbing molecules must incorporate the additional degrees of freedom. It is our opinion that experiments to date show that only extensive initial-state quantum selective experiments will enable a detailed mapping of the potential-energy hypersurface for  $H_2$  on copper, and the coupling of the translational and vibrational coordinates are the prime candidates for investigation.

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