

branching of fast/slow $\text{CH}_2 + \text{HCl}$ channels are shown in the lower panel in Fig. 26. The TOF spectra at mass 36 detected at photon energy from 15 eV to 21 eV can also be simulated using the same $P(E_T)$'s. The momentum match for the mass 14 and mass 36 products strongly suggests that signals at mass 14 and mass 36 should come from the $\text{CH}_2 + \text{HCl}$ channel. The fast channel is assigned to the $\text{CH}_2(\tilde{X}^3B_1) + \text{HCl}$ channel, the slower channel is assigned to the $\text{CH}_2(\tilde{a}^1A_1) + \text{HCl}$ channel.

Similar to the other two atomic channels, the majority (75%) of the available energy is deposited to the translational degree of freedom for the $\text{CH}_2(\tilde{X}^3B_1) + \text{HCl}$ channel, implying that this channel is more or less a direct and fast dissociation process. This is quite surprising for a molecular elimination channel since molecular elimination processes normally exhibit more statistical type behavior in which majority of the available energy is deposited into the internal degrees of freedom. For the slow $\text{CH}_2(\tilde{a}^1A_1) + \text{HCl}$ channel, the $P(E_T)$ peaks at about 30 kcal/mol with an available energy of about 80 kcal/mol. Therefore, the majority (~63%) of the available energy is distributed into the internal degrees of freedom for this channel, which implies that the dissociation of this channel is likely more statistical, unlike other dissociation pathways.

4. Future Outlook

We have witnessed significant progresses in the studies of crossed molecular reaction dynamics during the last decade or so. The improvement of the universal crossed beam apparatus based on electron impact ionization in our laboratory has propelled us into the studies of multiple channel dynamics of complex chemical reactions. Further improvement on this technique is certainly possible, but there are limits for such improvement since the basic limitation of detection sensitivity for this technique is from the electron space charge problem in the electron impact ionizer, in which electrons can only be packed to a limited density because electrons repel each other. However, some improvements are still possible, such as, closer detection distance and even larger quadrupole rod assembly. There is a possibility to improve the detection sensitivity by a few times, but that will have to sacrifice either the energy resolution or quadrupole mass range in the apparatus. Such improvement is certainly desirable if one wants to study radical-radical reactions.

The development of molecular beam apparatus based on VUV ionization has been a significant step in the studies of molecular reaction dynamics.

Even though the molecular beam apparatus at ALS or the new improved version at SRRC or the detection has not been fully exploited in the crossed beam reactive scattering studies, these apparatus certainly has demonstrated the power of the new technique in the photodissociation studies. Recent studies by Davis *et al.* on the CH₂ reactions with H₂ and other species have clearly demonstrated the power of the new method to measure radical products from crossed beam biomolecular reactions that are otherwise not detectable in the universal detection method.⁹¹ The VUV ionization as the diagnostic tool will also be important for development of new radical beam sources. One thing is certainly clear that the detection limit now is not limited by the VUV ionization method itself since photons can be focused, it is rather limited by the VUV photon flux from the third generation synchrotron radiation. Therefore the hope to improve the detection efficiency of such apparatus lies at the breakthrough of the VUV free electron laser technology, in which photon flux can be significantly enhanced by a few orders of magnitude. As it stands now, the SASE mechanism is likely the best hope for such a breakthrough in the VUV or X-ray free electron laser technology. The development of such lasers is already underway in a few laboratories in the world. If the VUV laser power can be enhanced by a few orders of magnitude, this will certainly revolutionize the molecular beam scattering research. At the moment, the prospects are good, but serious technical difficulties regarding these VUV free electron lasers still wait to be overcome.

Another development is certainly worthy to be exploited further. Molecular beam apparatus based on direct VUV laser ionization or resonance enhanced photoionization (REMPI) method can be a quite useful in the dynamics studies. Especially, such apparatuses are used with differential pumping between the source and the detector since source generated background is hard to eliminate without such differential pumping. Such scheme has been used by Davis *et al.* on the transition metal reactions with hydrocarbon molecules using 157 nm laser photoionization.⁹² Efficient REMPI detection can also be used in the future, such as H atom or others. Therefore further development in this direction is still quite promising in our view. Certainly, the application of the velocity map imaging technique⁹³ in the crossed beam reactive scattering studies will also continue to generate excitement in this research field. Therefore, even though the reaction dynamics field is quite mature already, future technology breakthrough could certainly benefit this field in a very significant way.