Final Report

Our research program focuses on the development of a method to cool atoms and molecules of any choice as long as they have a stable gaseous phase. Our approach starts with a very cold supersonic beam of He seeded with the molecules of choice. The internal temperature can reach 1 milliKelvin or less. The high center of mass velocity of the particles forming the beam will be reduced by elastically scattering the atoms/molecules from a very cold single crystal surface (20-40K), which moves in the beam direction. This will enable the continuous control of the mean velocity over a large range, after scattering, down to a few tens of m/s or even below as the crystal surface's velocity approaches v/2 of the impacting particles. We will use the decelerated particles as a source for a white-fringe matter-wave interferometer, where one reflector is a very cold surface of interest. The interference pattern will reveal the real part (via integral intensities) and the imaginary part (via phase shifts) of the scattering cross sections. This is particularly interesting for H_2 and resonance structures. This interferometer set-up follows closely Prichard's arrangement.

II Recent Progress

Figure 1 shows schematically the apparatus we are building to prove the feasibility of our ideas outlined above, i.e., to produce intense cold atomic and/or molecular beams without restrictions. There are two elements which are essential for our experiment. The first is

the reproduction of the ultra cold supersonic jet which has been reported twice. Velocities of 1000m/s and with a velocity spreads of 1m/s have been reported for helium. This corresponds to an internal energy of 1 milli-Kelvin. The second issue is the proof that a sufficient fraction of the particles in the jet scatter truly elastically from the moving surfaces. Note that in the center of mass system the incoming and outgoing velocity will be 500m/s. Only in the laboratory frame will the exit velocity be close to zero. We know from two previously published results that at very low temperatures the energy loss processes at the single crystal surface decrease and become irrelevant to us. In the language of the surface scientist; the Debye-Waller factor, which is the ratio of the elastic to total scattering, will approach unity. This limit will be reached at higher temperatures when the Debye temperature of the surface is high. Therefore we will try LiF ($\theta_D = 735K$) and MgO ($\theta_D = 925K$) to see if the asymptotic limit is already satisfied at liquid nitrogen temperature.. The reported limits so far are 40K for Cu ($\theta_D = 315K$) and Ag ($\theta_D = 215K$). A second option is to use a single crystal Au(111) surface. Its Debye temperature is much lower but the mass ratio of the mass of the crystal atoms and the beam particles enter the calculation and it will make up for more than we loose. Furthermore Au is repulsive against Hydrogen and we don't have to worry about any sticking (except for the residual gas).

There is also a technical challenge we had to solve. The rotor seen in figure 1 has to spin at 1.3 kHz at the low crystal temperature and in ultra high vacuum. There has been an arrangement reported, where a similar turret has been successfully rotated at 3.5 kHz at 77K. The critical issue is the balancing of the rotating crystal holder. At present our rotor

has been spun at 700 Hz in vacuum for several hours and with a rotation speed uncertainty of one milli-Hertz.

In addition we have proven that we can preserve the LiF surface at its cleaved purity by coating the freshly cut crystals with camphor. It will vaporize in the vacuum and we have shown with our quadrupole mass spectrometer that there is no thermal desorption when the crystal is heated up to 400C. (These results are summarized in a note, which is in print at Rev. Sci. Instr). Today the supersonic jet is working at liquid nitrogen temperature with pd values of 100 Torr-cm. In order to keep the crystal surfaces clean we have a CO_2 laser with 70 Watts aimed at the surfaces to ablate all impurities. This technique was successful as described previously.

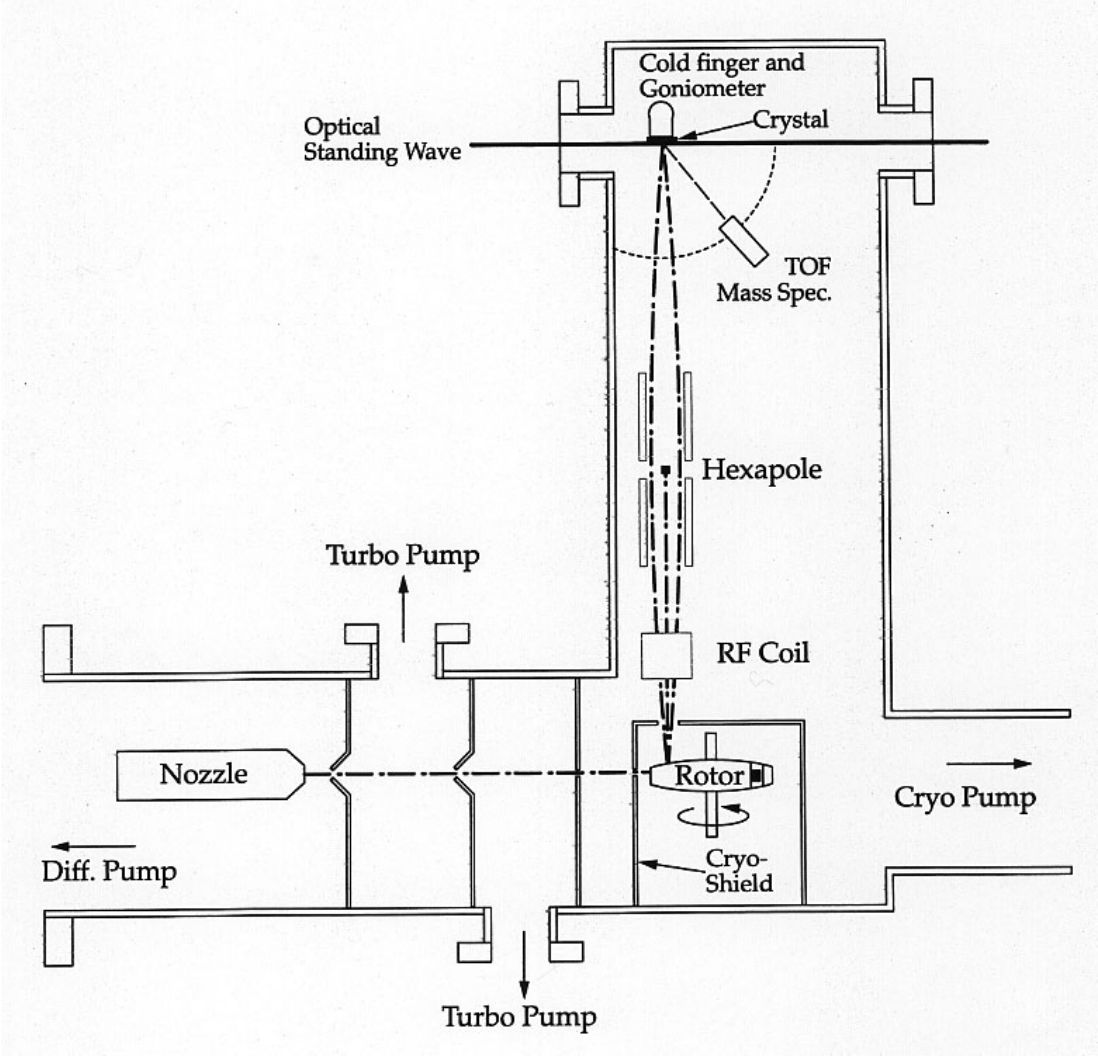

Figure 1

III Future Plans

Behind the rotor are two quadrupole mass spectrometers to derive the velocity of the particles from the position of the spectral lines and from the broadening the velocity spread. The spectrometers are currently 5 meters apart.

All efforts are currently focused on the production of slow helium atoms. Since we can control the velocities of the scattered He atoms with the rotor speed we also control the de Broglie wavelengths. We will use a SiN-grating to diffract the helium beam and evaluate qualitatively the properties of the slowed particles. We chose this technique since it is the first step toward the determination of the real and imaginary part of the scattering factors of He from single crystal surfaces. This will be done by recombining the first order beam with the specularly diffracted beam. The scattered intensity is expected to vary dramatically at discrete energies due to bound state resonances. These features have already been found previously by Boato. The first step toward unknown targets will be reached by using more interesting surfaces than pyrolytic graphite. The first molecules of choice are H_2, D_2, HD. Now we can see the influence of rotational and vibrational states on the bound states of the crystal surface. These states will be populated by resonance Raman pumping.