DENSITY PROFILES OF A SUPERSONIC JET TARGET*

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Summary

A supersonic jet target of $H_2(D_2)$ having an areal density of 5×10^{17} protons/cm^2 and 360° access in vacuum has been fabricated for use on the LAMPF NPL beam.

Introduction

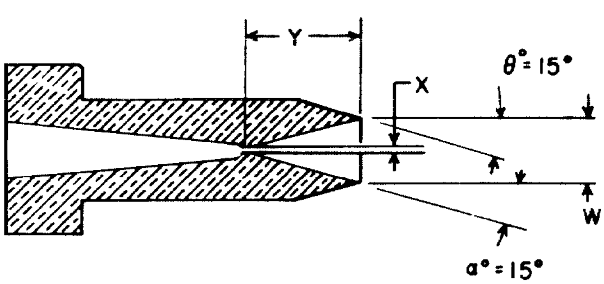
A classic problem of accelerator physics has been the production of a gaseous target which is sharply defined and can operate continuously in vacuum without the intervention of solid gas barriers (windows). Differentially pumped systems[1,2] approach this goal but leave much to be desired. Nikitin[3] and his colleagues developed a pulsed jet target for application in multi-GeV accelerators, and the study of such pulsed systems has continued.[4] For accelerators with appreciable duty cycles it is desirable to have a target which operates continuously. I have therefore studied such targets which have 360° access.

Apparatus

Jets can be formed by a variety of nozzle configurations. The axially symmetric Laval converging-diverging nozzle was employed in these studies. Dimensions of the jets were approximately set by the anticipated cross sections of the LAMPF NPL beam. Pertinent dimensions of the four nozzles studied are displayed in Fig. 1. Fabrication of nozzles with the indicated throat sizes occasioned some difficulties. Some were made by standard boring techniques. Others were made by turning a mandrel whose contour was that prescribed for the inside of the nozzle and then electroplating the nozzle walls on the mandrel with subsequent etching out of the mandrel. In either case throat diameters could be made with approximately 15% accuracy and may depart that much from circularity. Final throat contours are obtained from shadowgraph observations of plastic throat molds. The jets traversed a 5-mm gap and were collected in a cone whose entrance aperture was 20 mm in diameter and whose 1/2 angle was 12°. The receiving cone was pumped by a 4000 CFM Roots Blower. The small fraction of the gas which did not enter the receiver was pumped out of the vacuum tank by two liquid nitrogen baffled diffusion pumps whose combined capacity for hydrogen was 8×10^4 ℓ/s. Nozzle input pressures below 2400 psi were supplied from gas cylinders; above 2400 psi a booster pump was employed. Pressure in the vacuum tank was monitored by an ionization gauge located approximately 1 m from the jet. Areal densities in the jet were obtained from total absorption measurements on a beam of 584 Å photons whose 1/2 power width was 0.2 mm at the jet. The photons were generated in a low pressure capillary discharge[5] of helium, the 584 Å radiation being dominant. The discharge was dc excited by a stabilized supply. Photons left the source via a two-stage differentially pumped collimator which defined the beam diameter. After passing through the jet the photon beam traversed a 1000 Å thick filter of Sn or Sb and was detected by a channeltron which drove a pulse amplifier whose output was counted by a 50-MHz scaler. Under the very best conditions the entire system of source plus detector was stable to 1/2%/hr. Channeltrons having ends open or closed were used. Tests in other systems indicated they contributed negligibly to the drift. Drift corrections were generally required. A measurement of 10^5 cpm was typical. Until recently, the appropriate photoabsorption cross section for H_2 and D_2 was rather uncertain. The uncertainty now[6] is approximately 2%. The UV source, absorber, and channeltron were rigidly attached to a common stage which could be remotely translated vertically and horizontally. Digital readout of the photon beam coordinates was provided. The disposition of the components of the experiment is indicated in Fig. 2.

Data

Measurements were concerned primarily with the nozzles having throat diameters of 0.051, 0.076, and 0.10 mm. Transverse scans of the jets were performed at 0.5 mm (upper) and 4.0 mm (lower) below the nozzle exit. The input temperature of the gas was 294°K±2%.



W	X	Y
0.42	0.010	0.76
0.41	0.0076	0.76
0.41	0.0051	0.76
0.82	0.0025	1.5

Centimeters

Figure 1

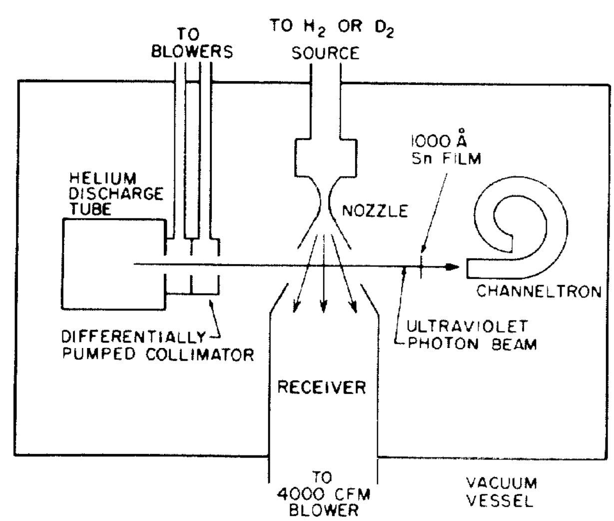


Figure 2

*Work performed under the auspices of the USAEC.

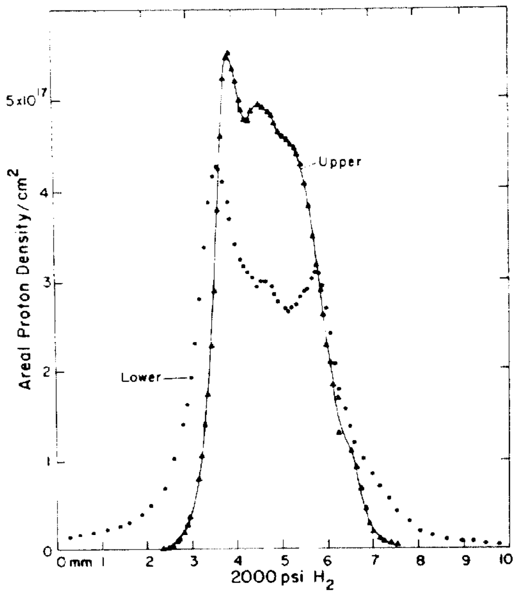


Figure 3

The input pressures were measured to 1%. Jet profiles for the 0.076-mm nozzle at 2000 psi H_2 are given in Fig. 3. These profiles reproduce to a high degree of precision. No indication of instability has ever been noted except once when the jet apparently collapsed during a rapid start and flooded the vacuum tank. These profiles indicate a slight departure from axial symmetry. This may be a consequence of the fact the jet exhaust line makes a right angle bend immediately below the receiver which results in an asymmetric shock structure in the jet. In Fig. 4 are profiles for 1000 psi H_2 input to the same nozzle. The ratio of the integrated densities, as determined from the UV absorption measurements, is $\int\rho_{2000}/\int\rho_{1000} = 0.99\times 2$. At 2000 psi the flow rate, determined from a pressure-flow calibration of the exhaust line, was 1.43 scfm. The corresponding ratio of flow rates was 1.01×2. Similar flow measurements on the 0.0025-mm nozzle established that the flow rate was proportional to the pressure to better than 2% over the input range 1000 to 5000 psi H_2. The hot core of the LAMPF NPL beam can be 1 mm in diameter; hence, this jet is a good match. A jet formed by the 0.05-mm nozzle has the profile shown in Fig. 5. Evidently it has expanded to the point where separation from the nozzle walls occurs. The average

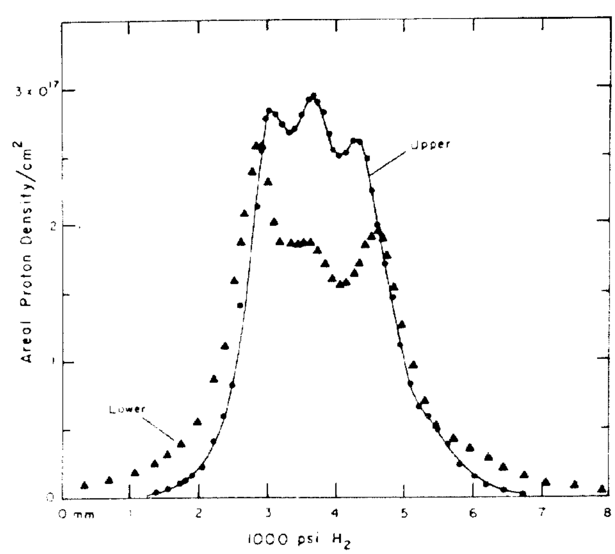


Figure 4

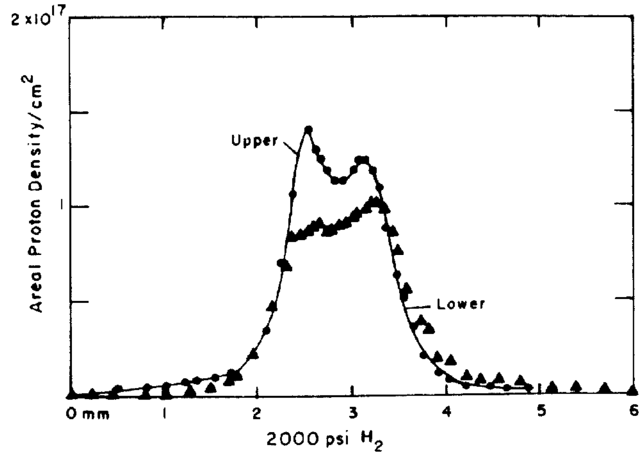


Figure 5

velocity of the gas inferred from density and flow measurements is 2.6×10^5 cm/sec. An exact calculation is quite difficult. Dimov[7] has given the estimate 2.75×10^5 cm/sec as the maximum velocity for hydrogen. The profile of a deuterium jet formed by the 0.01-mm nozzle is displayed in Fig. 6. Satisfactory operation with helium was observed but no quantitative measurements were made. Such measurements can be made by utilizing the 304 Å photons from the capillary discharge. The behavior of the ambient tank vacuum for the nozzles is shown in Fig. 7. For the deuterium observation the tank vacuum gauge indicated 1.5×10^{-5} T.

Epilogue

It is clear from this work that continuously operating supersonic jet targets with 360° windowless access are feasible for accelerators. Moreover, it may be possible to accommodate very large depositions of beam power in supersonic jet targets[8] such that neutron fluences several orders of magnitude higher than currently obtainable values may be achieved. Such targets should open up new domains of research in nuclear physics as well as optical and plasma physics.

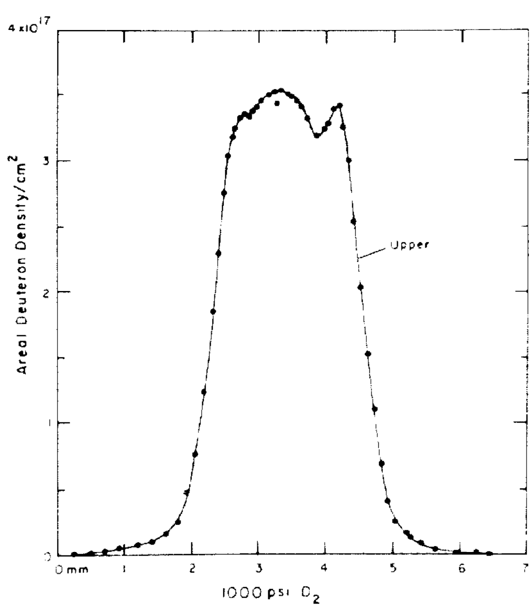


Figure 6

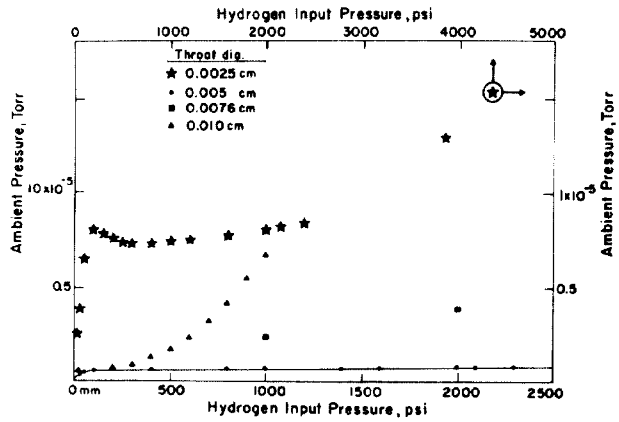


Figure 7

Acknowledgements

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