Production of a high-density state-selected metastable neon beam

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We have developed a high-density source of metastable neon and have selectively quenched both metastable species using a standing-wave dye laser. The source is compact, stable, and produces an average intensity of 3.6×10^{14} sr^{-1} s^{-1} and a density on target of 7.7×10^{6} cm^{-3}.

I. INTRODUCTION

We are interested in performing polarized electron scattering experiments on specific J states of metastable neon. The count rates for these experiments would be prohibitively low using present techniques, primarily because of low target density. To this end we have developed a new metastable atom source/target configuration employing a cold-cathode flowing afterglow as developed by Fahey *et al.*[1] which produces a high metastable atom target density. Since two metastable states ($^3P_2$ and $^3P_0$) are produced in the discharge it is necessary to quench the one that is not of interest.[2]

Quenching of a given metastable state is accomplished by optically exciting it to one of the states of the $2p^5 3p^1$ manifold as shown in Fig. 1. The state may then decay back to the original state, to the other metastable state (conversion), or to the $J=1$ states ($2p^5 3s\ ^3P_1$, $^1P_1$), which can in turn decay to the ground state. The best quenching line for a given experiment is determined by the absorption probability, the branching ratios for the three decay processes, and the power available at the various wavelengths. We have studied all the quenching transitions obtainable with our laser system[4] and have found best results using the 6134 Å and 6163 Å lines for the $^3P_2$ and $^3P_0$ levels, respectively. Unpolarized light is used so that all magnetic levels are pumped without alignment effects.[5]

II. EXPERIMENTAL APPARATUS

The apparatus is shown in Figs. 2 and 3. Neon gas at 200 Torr flows through the boron nitride nozzle (150 μm diameter). A discharge is struck between the tungsten "brush" cathode, placed behind the nozzle, and the skimmer which has a 600-μm-diam aperture. The cathode is maintained at 600 V, producing a typical discharge current of 25 mA. The spacings between the cathode, nozzle, and skimmer are adjustable but the metastable flux is relatively insensitive to them. Typically the end of the cathode is 5 mm from the end of the nozzle which is 1 cm from the tip of the skimmer. Alignment of the nozzle with respect to the skimmer is critical; the nozzle is mounted on a sliding O-ring flange and is adjusted with a 2D translation stage on the rear of the source chamber. Source pressures are maintained at $\sim1\times10^{-4}$ Torr by a 4 in. diffusion pump placed immediately below the discharge region. Because of the low conductance of the nozzle and skimmer and the high pumping speed of this arrangement, the experiment can be performed in the next chamber which is maintained at $\sim1\times10^{-6}$ Torr by a second 4 in. diffusion pump. Good vacuum (i.e., high pumping speed) was also crucial for production of high fluxes, presumably because of the effects of both elastic scattering and energy transfer collisions.

For test purposes, a cross for optical quenching and a secondary-electron emission detector are mounted at the exit of the chamber. The results reported in this note assume unit efficiency for production of secondary electrons by metastable atoms. This is conservative and our actual intensities could be higher by as much as a factor of 3.[6] In the final configuration a multiple-pass optical cavity will be installed directly after the skimmer and the detector will be replaced with a Stern–Gerlach analyzer. Charged particles are swept out of the beam by deflection plates.

The quenching is performed with a particularly simple optical system using a Spectra Physics 375B standing-wave dye laser (using Rhodamine 6 G dye) with a three-plate birefringent filter and thin etalon to reduce the bandwidth to 7 GHz. When pumped by a 6-W argon-ion laser (Spectra Physics model 2010) it produces ~400 mW at the 6143 and 6163 Å transitions. The output from the dye laser is sent through an rf neon discharge cell which displays a bright resonance fluorescence and thus serves as an in-line wavemeter. The beam is then piped to the atomic beam through a 30-m-long, 200-μm core-fiber-optic cable which also serves as a depolarizer. It is then collimated and focused onto the beamline with a cylindrical lens. A spherical mirror is placed underneath the cross to cause a second intersection of the two beams. With this arrangement we estimate that ~150 mW of laser light intersects the atomic beam.

The metastable flux is dependent on both discharge current and nozzle pressure, with operating ranges between 3–25 mA and 50–300 Torr, respectively. A maximum flux was obtained at 200 Torr and 25 mA. The source is very stable; it has no short-term intensity fluctuations and the long-term intensity drift is less than 5% over 12 h.

III. RESULTS AND CONCLUSIONS

Figure 4 shows the power curves for quenching of both metastable states. These curves were obtained by inserting a series of neutral density filters in the laser beam while operating at maximum laser power. For the 6163-Å tran-

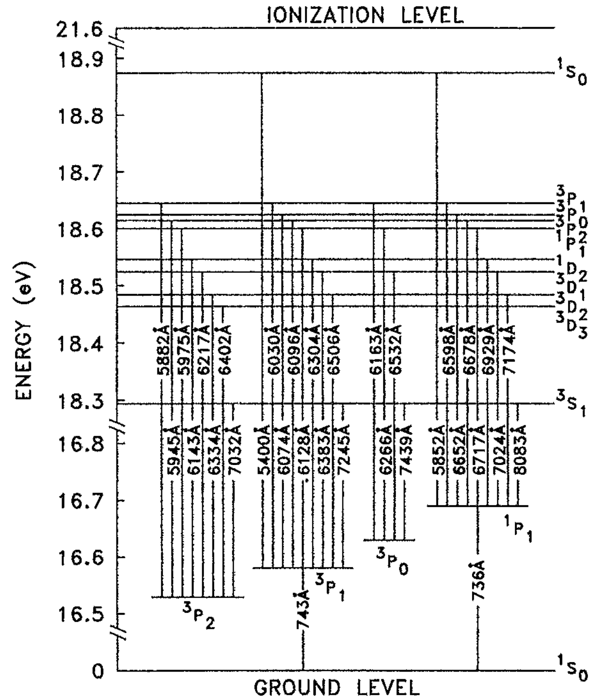

FIG. 1. Energy diagram for first two excited states of neon (after Fig. 1 of Ref. 3).

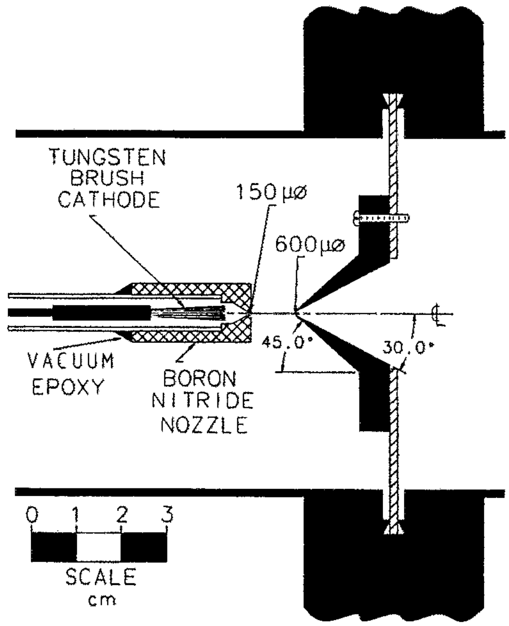

FIG. 3. Detail of nozzle and skimmer. Diagram is to scale.

sition, 29% of the $^3P_0$ metastables quenched are actually converted to the $^3P_2$ state and are still recorded by the detector. Thus the $^3P_0$ data have been multiplied by a factor of 1.4 to correct for this effect. At our maximum available power 84% of the beam signal can be quenched. By bleeding neon into the target region to attenuate the metastable flux, we found that the contribution of photons to the beam signal was roughly 12%.[7] We expect no contamination from fast neutrals since any ions created in the discharge will be accelerated upstream toward the tungsten cathode. There should also be negligible contamination by long-lived high-n Rydberg atoms since they would have to pass through an electric field at the deflection plates. No change in the beam signal was observed when we varied this field from 0 to 200 V cm^{-1}. Thus ~95% of the metastable beam is quenched by the laser, a result consistent with that of Ref. 8. We estimate that the ratio of ground-state atoms to metastables is ~10^5 similar to other sources of this type.[9] Our results were obtained without stabilization of the dye laser and without dithering the frequency as reported by Lynn *et al.*[10] It is probable that by employing these techniques more complete quenching would be observed.

The source produces the highest flux of neon metastables observed to date: 3.6×10^{14} sr^{-1} s^{-1}. We note that this number is an average, and not a line-center flux, and

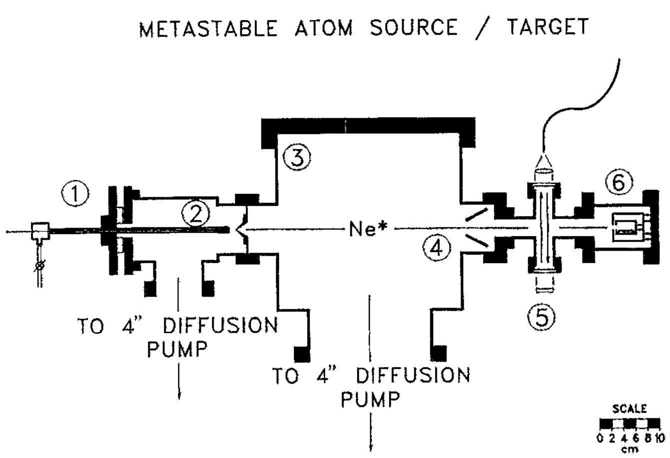

FIG. 2. Scale drawing of metastable source and target chamber. (1) Gas handling system and alignment flange; (2) nozzle and skimmer; (3) target chamber; (4) electron-deflection plates; (5) optical-quenching cross; (6) secondary-electron detector.

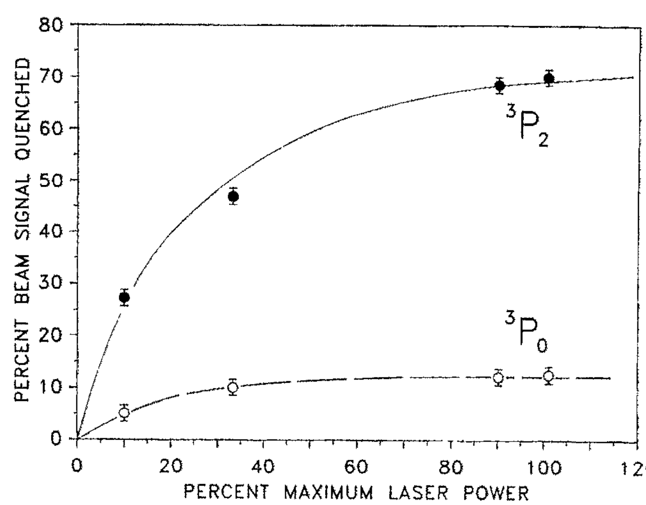

FIG. 4. Beam signal quenched vs percentage of maximum (~150 mW) laser power (see text).

again that it is a lower limit on the flux given our assumption of unit metastable detection efficiency. The flux is higher than that observed by Verheijen *et al.*[9] by a factor of 20, higher than that of Fahey *et al.*[1] by a factor of 2.7, and slightly higher than the flux of 3×10^{14} sr^{-1} s^{-1} reported by Hotop *et al.*[8] More important to us than high flux is the high metastable density available in the target region, calculated using

$$n=I/\bar{v}r^2, \qquad (1)$$

where I is the average detected flux, $\bar{v}$ is the mean velocity equal to $\sim8.5\times10^4$ cm^{-1},[11] and r is 22 cm, the distance from the nozzle to the target center. This results in a density of 7.7×10^6 cm^{-3}. Argon and helium metastable production were also examined, and results were typically in the ratio of 4:2:1 for He*:Ne*:Ar*, consistent with other findings.[9]

In summary, the high density available with this apparatus is due to low pressure in the source chamber, close proximity of the source of the target, and precise alignment of nozzle with respect to the skimmer. The compactness and simplicity of this configuration, particularly with regard to the source and optical components, make it especially attractive.

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