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High Efficiency Hyperfine Pumping of Cesium Vapor

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The hyperfine pumping of cesium vapor has been obtained by using a magnetic filter for the pumping light. The filter transmits the hyperfine component of the D_1 resonance line which starts from the $F=4$ sublevel of the ground state. The level which is populated with the hyperfine pumping is therefore that with $F=3$. Neon has been used as a buffer gas, and the best results were obtained for a pressure of 20 Torr. In this condition, 15% of the Cs atoms in the hyperfine level $F=4$ are transferred into the $F=3$ level. The relaxation time, as a function of Cs vapor density, has been measured for five values of the neon pressure, and the Cs-Cs spin-exchange cross section has been determined to be $(2.20\pm0.15)\times10^{-14}$ cm^2.

THE hyperfine optical pumping in the ground state of the alkali metals requires a good filtering of one of the hyperfine components of a D line. No efficient method exists for obtaining such a filtering, except for rubidium. For rubidium one uses the isotope shift of the resonance lines between ^{85}Rb and ^{87}Rb.[1] We were able to obtain hyperfine pumping of Cs vapor by using a magnetic filter constructed in our laboratory.[2] The efficiency of this type of filter is good, perhaps better than that of a ^{85}Rb filter for the ^{87}Rb.[3] The D_1 pumping light after passing the filter cell contains only the component which starts from the hyperfine level of the ground state with higher F ($F=4$ for Cs). The optical pumping leads then to a depopulation of this level in favor of the level with lower F ($F=3$ for Cs). A large population difference between the ground-state hyperfine levels can be obtained, and the hyperfine relaxation can be studied.

A sketch of the experimental apparatus is shown in Fig. 1. All the cylindrical Pyrex cells used in this experiment were 8 cm long with a radius of 3 cm. The relaxation times were measured by Franzen's method.[4] A silicon cell was used instead of a photomultiplier in order to minimize the low transient response of the detector.[5]

As explained in Ref. 2, the magnetic filter works with linearly polarized light. The cell is placed in a weak magnetic field orthogonal to the direction of the pumping beam and at about 45° with respect to polarization of the pumping light. In this way the transitions π and σ are equally probable and there is no possibility of creating an alignment in addition to the hyperfine pumping. We can infer the fraction of the atoms transferred from the level $F=4$ to the level $F=3$ by measuring the pumping signal.

As a buffer gas, we used neon at a pressure of 74.0, 37.2, 28.0, 18.2, and 10.7 Torr at 0°C. At 15°C (low Cs vapor density) and 18.2 Torr of neon, 15% of the atoms of the sublevel $F=4$ are transferred into the level $F=3$. At higher temperatures, the pumping efficiency decreases because of spin-exchange relaxation. At 33°C it reduces to about 2%. No pumping signal was obtained when using cells coated with methylhydrogenpolisiloxane and without a buffer gas. A very small signal was obtained using a cell coated with dimethylpolisiloxane and without a buffer gas. It is worth noting that we have obtained a good optical pumping of Na and Rb in cells coated with dimethylpolisiloxane. The failure in the case of cesium is probably due to the greater chemical reactivity of cesium. This is in agreement with the results obtained with the stored-beam technique.[6]

We can calculate the spin-exchange cross section between Cs atoms from the measured value of the relaxation time of the quantity $\langle \mathbf{S}\cdot\mathbf{I}\rangle$, i.e., of the hyperfine pumping. Since $\langle \mathbf{S}\cdot\mathbf{I}\rangle$ relaxes with only one time constant,[7] we can put

$$1/\tau=1/\tau_0+1/\tau_{\rm ex},$$

where τ is the total observed relaxation time, $1/\tau_0$ is the relaxation probability due to collisions between Cs

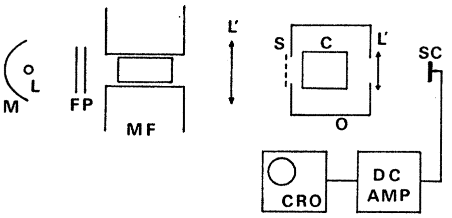

FIG. 1. Experimental apparatus: C, cell; F, D_1 filter; L, lamp; L', lens; M, mirror; MF, magnetic filter; O, oven; P, linear polarizer; S, shutter; SC, silicon cell.

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atoms and the buffer gas atoms or the cell's walls, and $1/\tau_{\text{ex}}$ is the relaxation probability due to the spin-exchange collisions. $1/\tau_{\text{ex}}$ is proportional to the density of the Cs atoms while τ_0 is practically independent of the temperature of the cell. A temperature dependence of τ_0 appears at higher pressures of the buffer gas, and it is due to the diffusion process which prevents the uniform distribution of the pumped atoms in the cell.[8] At low pressure, however, this effect is negligible. This has been directly tested, at the above values of the buffer gas pressure, in the following way. The Cs vapor was also pumped with unfiltered and circularly polarized D_1 light at several temperatures. The relaxation of the quantity $\langle \mathbf{S}_z \rangle$ was then measured, which is independent of the spin-exchange collisions. The diffusion problem is identical for both $\langle \mathbf{S}\cdot\mathbf{I} \rangle$ and $\langle \mathbf{S}_z \rangle$, if the corresponding relaxation times are of the same order of magnitude. Then, if the relaxation time of $\langle \mathbf{S}_z \rangle$ is found to be temperature-independent, τ_0 is also temperature-independent. This was found to be the case at 10.7, 18.2, 28.0 and 37.2 Torr of neon. A temperature dependence appears at 74.0 Torr of neon. Then for the first four pressures of neon the spin-exchange cross section can be calculated by the formula

$$\sigma_{\text{ex}} = \frac{\Delta(1/\tau)}{\Delta N}\,\frac{1}{V},$$

where $V = 4[RT/\pi M]^{1/2}$ is the mean relative velocity of the Cs atoms, if several values of $1/\tau$ and corresponding densities of the cesium vapor are determined. The value $1/\tau$, extrapolated to zero vapor pressure, gives $1/\tau_0$. The measurements were made in the range of temperatures between 13 and 35°C. For higher temperatures the optical pumping signal was strongly diminished and the relaxation time was so short that it proved too difficult to measure it.

A plot of the measured values of $1/\tau$ versus N (number of Cs atoms per cm^3) is given in Fig. 2. The values of N were calculated using the Taylor-Langmuir formulas.[9] The value of σ_{ex} between Cs atoms determined in this way was found to be

$$\sigma_{\text{ex}} = (2.20 \pm 0.15) \times 10^{-14}\ \text{cm}^2.$$

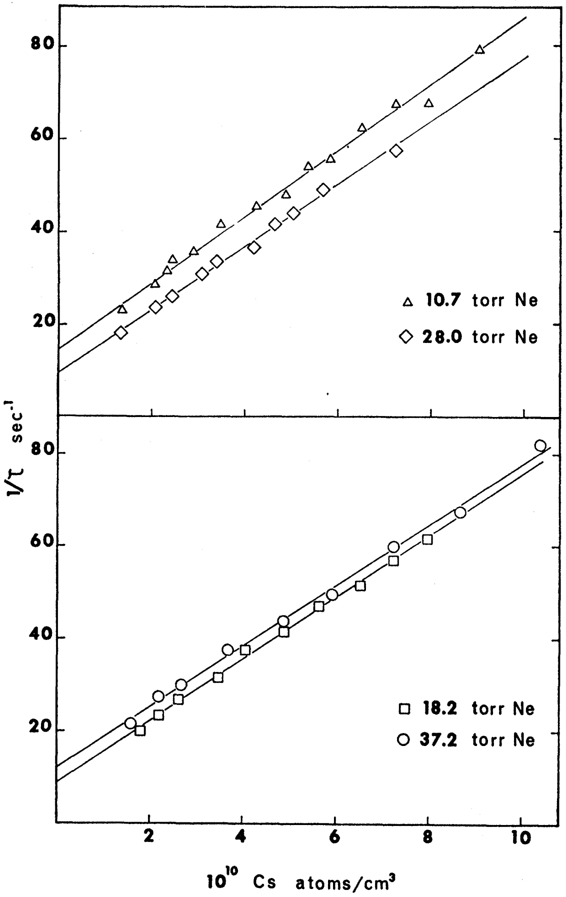

FIG. 2. The measured values of $1/\tau$ are plotted as a function of the density of the Cs atoms. The values of σ_{ex} obtained are $(2.31 \pm 0.20) \times 10^{-14}$, $(2.16 \pm 0.20) \times 10^{-14}$, $(2.20 \pm 0.20) \times 10^{-14}$, and $(2.13 \pm 0.20) \times 10^{-14}$ cm^2, respectively, for pressures of 10.7, 18.2, 28.0, 37.2 Torr of neon.

The main source of error is due to the uncertainty of the density of the saturated cesium vapor.

Our value is in good agreement with that obtained by Bouchiat and Grossetete.[10] Also, Moos and Sands[11] obtained in a completely different way a value in agreement with ours.

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