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WALL RELAXATION RATES FOR AN OPTICALLY PUMPED NA VAPOR

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ABSTRACT

The wall relaxation rates for an optically pumped Na vapor have been measured for a variety of wall surfaces. We find that fluorocarbon rubber (Fluorel, Viton) and organosilicones (silicone rubber, dry film) at a temperature of 250 C have respectively relaxation rates that correspond on the average to 10-15 and 200-500 bounces before depolarization occurs.

Research on wall relaxation rates for an optically pumped polarized alkali vapor is of interest. This paper reports wall relaxation rates for optically pumped Na atoms colliding with a number of different surfaces. In particular this paper reports the discovery that, on the average, a polarized Na atom can make many collisions with a fluorocarbon rubber (Fluorel, Viton) or organosilicone (silicone rubber, dry film) surface before depolarizing. These are the first low relaxation rate surfaces found that have a low vapor pressure and sufficient structural integrity at temperatures of 200-300 C to be useful for polarized Na vapor. A current application for a polarized Na vapor is as the charge exchange target used in the production of polarized H^- ions.

In the optically pumped polarized H^- ion source, H^+ ions are incident on an optically pumped polarized Na vapor target where they pick up a polarized electron forming a fast electron spin polarized H atom [1-5]. The polarization is transferred to the nucleus [6], and some of the fast H atoms are converted to polarized H^- ions in a second alkali target. The H^- ion current and polarization respectively can be increased if the density and polarization of the optically pumped Na vapor target can be increased. In the optically pumped Na target used in the polarized H^- ion source, the target density and polarization are limited by both the laser power and the wall relaxation rate. Thus the discovery of wall surfaces with small relaxation rates offers promise of improved performance for the optically pumped polarized H^- ion source. In order for a wall surface to be useful for the polarized Na target used in the polarized H^- ion source the wall surface must have good vacuum properties such as a low vapor pressure at the operating temperature of the target, which is 200-300 C. This is required so that the H^+ ions pick up an electron only from the optically pumped Na and not from unpolarized background gas. Also the wall must have adequate structural integrity at the operating temperature of the target, and the wall should not react with the alkali vapor.

Surface relaxation rates for a Na vapor have not previously been studied extensively. There have been, however, extensive studies of surfaces with a small relaxation rate for a Rb vapor. Bouchiat and Brossel [7] have studied the relaxation of optically pumped Rb atoms on parafin-coated surfaces. They have found that there are two different relaxation mechanisms for Rb on paraffin surfaces. One was identified as the dipole-dipole interaction between the electron spin of the Rb atom and the nuclear spins in the wall coating. The second was not identified with certainty, but they speculate that it is a spin orbit interaction. The low field relaxation of the electron spin $\langle S_z \rangle$ is due to both interactions.

Both high field relaxation of $\langle S_z \rangle$ and the low field relaxation of the hyperfine level population difference <S*I>, at low Rb atom density, are almost entirely due to the second interaction. Thus the high field relaxation rate of $\langle S_z \rangle$ and the low field relaxation rate of <S*I> at low alkali density are the same. The relaxation rate of <S*I> varies linearly with the alkali atom density due to spin exchange collisions. The relaxation rate of $\langle S_z \rangle$ is only slightly affected by spin exchange. The paraffin coated surfaces used by Bouchiat and Brossel are unsatisfactory at the temperatures required for the Na vapor target used in the optically pumped polarized H^- ion source. We measure the relaxation rate for <S*I> as follows. We generate an intense pump beam that is absorbed by one of the ground hyperfine levels thereby pumping the atoms into the other hyperfine level. When this beam is suddenly cut off the Na vapor relaxes. The weak probe beam measures the relaxation as a function of time. A schematic of our apparatus is shown in Fig. 1.

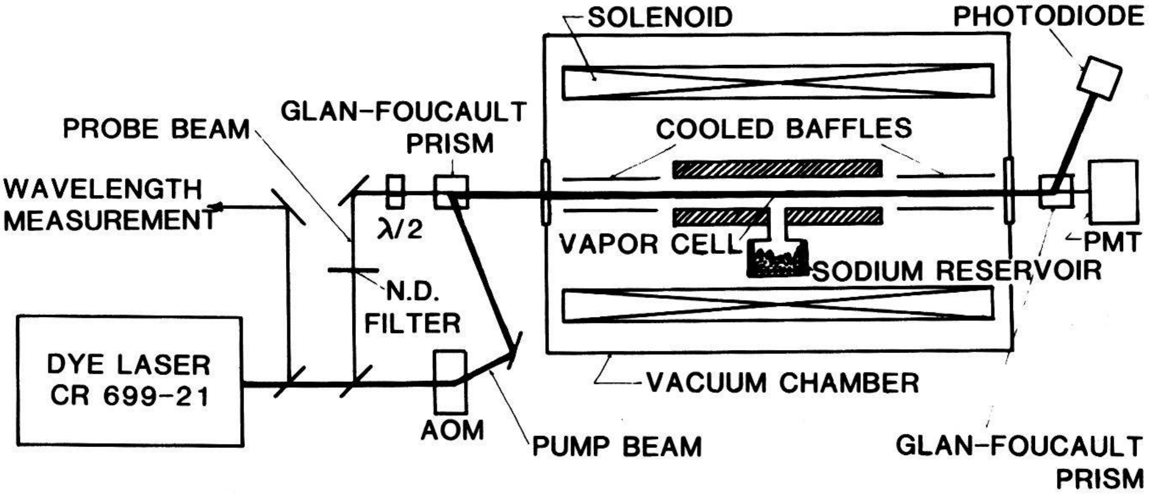

Fig. 1. A schematic diagram of the apparatus. The beam from a dye laser is split to form an intense pump beam and a very weak probe beam. The pump and probe beams have orthogonal linear polarizations. The beams are combined in a Glan-Foucault prism and pass through the Na vapor along the same path. After the target they are split by a second Glan-Foucault prism. The output of the photomultipler, which detects the probe beam, is recorded using a transient digitizer.

The Na vapor target is a tube with an inner diameter D and a length of 15 cm. The target is made of stainless steel, and the walls of the target are easily changed by sliding in liners. The Na target is located inside a vacuum chamber where the pressure is maintained at 10^{-6} Torr or less. Glass windows in the vacuum chamber permit the dye laser beams to pass along the axis of the Na target. The Na target is in a weak magnetic field (1-20 Gauss) that is parallel to the axis of the target. The Na vapor enters the target from the reservoir through a hole about 2 mm in diameter at the center of the target. The Na density is maintained very low outside the target by cooled baffles at each end of the target. The temperatures of the target and the Na reservoir are measured with thermocouples. The temperature of the target is maintained about 25 C hotter than the temperature of the Na reservoir to prevent condensation of Na in the target.

We have measured the relaxation time, T_{1e}, of <S*I> for Na vapor relaxing on several wall surfaces. The relaxation rate T_{1e}^{-1} is given by $T_{1e}^{-1} = T_1^{-1} + T_P^{-1}$ where T_1^{-1} is the wall relaxation rate and T_P^{-1} is the flow rate of Na atoms out of the target tube. From the temperature and geometry of our target we calculate the conductance for molecular flow out of the target. Using the conductance we calculate T_P^{-1}. From the measured T_{1e}^{-1} and the calculated T_P^{-1} we obtain T_1^{-1}. Figure 2 shows typical data obtained in measuring T_{1e}. The relaxation times T_1 for <S*I> on various surfaces are given in Table I.

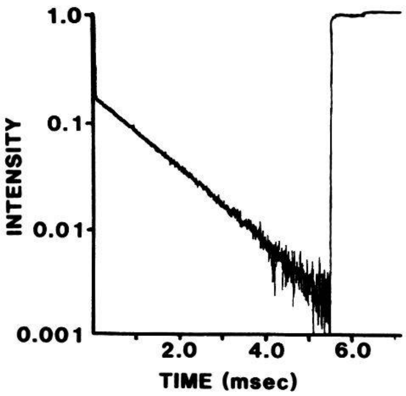

Fig. 2. Experimental data showing a semi-log plot of transmission of probe beam as a function of time after the pump beam was cut off. T_{1e} = 1.3 ms and T_1 = 2.07 ms. which corresponds to 490 bounces before depolarization.

Table I. Na vapor wall relaxation times. The relaxation time has been converted into the number of wall collisions before relaxation.

MATERIAL	NUMBER OF BOUNCES
stainless steel (250 C)	1
graphite (250 C)	1
anodized aluminum (250 C)	1
chrome plated copper (250 C)	1
teflon (200 C)	1
Kel-F (200 C)	1
Kapton (250 C)	1
polyethylene (125 C	15
fluorocarbon rubber (250 C)	
Viton	20
Fluorel	15
silicone rubber (225 C)	150
RTV 3145 (250 C)	200
"dry film" (275 C)	
on glass $(CH_3)_3SiC\ell$, $(CH_3)_2SiC\ell_2$	>250
on copper $(CH_3)_2Si(OCH_3)_2$, $CH_3Si(OCH_3)_3$	450

For our geometry the flight time between collisions is approximately D/v where D is the inner diameter of the liner and v is the thermal velocity of a Na atom. For our liners the flight time between collisions is $(4-18) \times 10^{-6}$s, depending on the thickness of the liner. The relaxation times for all metal surfaces and for teflon and kapton surfaces were measured to be about 10^{-5}s. This indicates that the atoms relax completely at each wall collision. However for polyethylene, fluorocarbon rubber, silicone rubber and dry film, the relaxation times are observed to be longer than 10^{-5}s. Polyethylene is not useful at the temperatures necessary for a Na target used in the optically pumped polarized H^- ion source. The other materials are useful at temperatures up to 300 C. All, however, degrade with time. Silicone rubber (RTV 3145) and fluorocarbon rubber lasted over a week at 250 C, after which time, the relaxation time was reduced to approximately one bounce. At temperatures above 300 C reactions with Na occur rapidly with both fluorocarbon rubber and silicone rubber. On the other hand, dry film on glass has excellent vacuum properties and is relatively inert in the presence of Na. Figure 3 shows the relaxation time, T_1 for dry film on glass as a function of the time of exposure to Na at 225 C. Dry film on metal does not seem to last as long as dry film on glass.

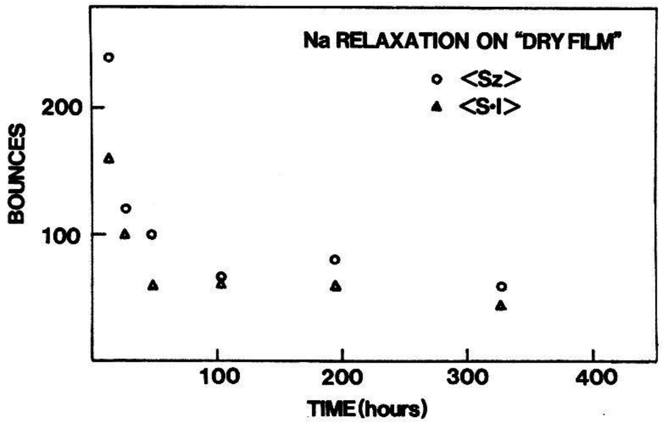

Fig. 3. Wall relaxation time as a function of time of exposure to Na at 225 C for dry film on glass

The Na atom density in our target is calculated from the measured reservoir and target temperatures and the known vapor pressure of Na as a function of the temperature. At low density the relaxation times for fluorocarbon rubber and organosilicones correspond respectively to approximately 10-15 and 200-500 wall collisions respectively before relaxation occurs. Because of the uncertainty in our measurements of T_{1e} and the uncertainty in the target atom density, we have not yet accurately determined the spin exchange cross section for Na-Na collisions from the relaxation rate as a function of the temperature.

We have not measured the relaxation of $\langle S_z \rangle$ in a high magnetic field. Based on the theoretical analysis of Bouchiat and Brossel we expect that the high field relaxation rate of $\langle S_z \rangle$ will be nearly the same as the low field relaxation rate of $\langle S*I \rangle$. If this is the case then either a fluorocarbon rubber or organosilicone surface will be useful for the optically pumped Na target in a polarized H^- ion source.

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