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Atomic manganese ^{55}Mn and chromium ^{52}Cr are simultaneously loaded and confined in a magnetic trap. Using a cryogenic ^{3}He buffer gas, 10^{11} manganese and 10^{12} chromium atoms are trapped at an initial temperature of 600 mK. The buffer gas is then pumped away, thermally isolating the sample. The Mn-Cr interspecies inelastic rate constant is measured to be $\Gamma_{\mathrm{Mn,Cr}}=1.5(\pm0.2)\times10^{-13}\,\mathrm{cm}^3/\mathrm{s}$.

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The ability to simultaneously cool and trap multiple species has paved the way for the exploration of a variety of physical phenomena not previously accessible with a single species. Photoassociation in dual species traps has produced ultracold heteronuclear molecules [1,2]. Sympathetic cooling of multiple trapped species has yielded Fermi degenerate gases and Fermi-Bose mixtures [3–7]. All previous trapping of binary mixtures utilized laser cooling to initially load a magnetic trap. Laser cooling, however, requires that the atom has a strong cycling transition at an accessible wavelength; it has thus far been limited to binary mixtures of either alkali metals or metastable noble gases [8]. Buffer-gas cooling and trapping does not have the same limitations [9].

In this work, we simultaneously trap atomic manganese and chromium using buffer-gas cooling. Beyond this general demonstration of dual-species trapping, the Mn-Cr mixture has particular properties of interest. A binary mixture of manganese and chromium in the quantum degenerate state could have significant dipolar effects [10]. Furthermore, it might be possible to, via a Feshbach resonance or photoassociation, produce an electric dipolar molecule with very high magnetic moment—an interesting species for studies of dipolar effects in quantum matter. In addition to co-trapping Mn and Cr, we measured the Mn-Cr inelastic rate constant—an important parameter in the initial co-evaporative cooling of these species, the first step toward a degenerate mixed gas of Mn and Cr.

The apparatus, shown in Fig. 1, is described in detail in Ref. [11]. Mn and Cr atoms are produced via laser ablation of solid metal targets inside a cylindrical plastic/copper composite cell maintained at 600 mK by a ^{3}He refrigerator through a copper thermal link. The cell fits coaxially inside the bore of a superconducting anti-Helmholtz magnet, creating a spherical quadrupole trap with a depth of 3.5 T. A valve separates the trapping region from a pumping region filled with ~30 g of activated charcoal cooled to a temperature of 1.5 K.

With the valve initially closed, the cell is filled with ^{3}He gas at a typical density of $10^{16}\,\mathrm{cm}^{-3}$, determined by measuring the diffusion time of Cr through the cell at zero magnetic field [12]. The beam from a pulsed frequency-doubled Nd:YAG laser is split in two by a 50/50 beam splitter, and each beam, with a typical energy of 5 mJ, is focused onto its respective metal target, Mn or Cr. Roughly 10^{13} Cr atoms and 10^{12} Mn atoms are produced in the ablation. Both Cr and Mn atoms quickly thermalize with the ^{3}He buffer gas, and the low-field-seeking atoms fall into the magnetic trap while the high-field-seeking atoms are lost to the cell walls. The valve is fully opened in 20 ms. The ^{3}He buffer gas is pumped away onto the charcoal sorb, leaving behind the Cr and Mn atoms in the magnetic trap. At the trap depth used, effects from the rapid removal of the buffer gas are negligible [11].

The atoms are detected via laser absorption spectroscopy using Cr's $^7S_3\rightarrow{}^7P_4$ transition at 425 nm and Mn's $^6S_{5/2}\rightarrow{}^6P_{7/2}$ transition at 403 nm. Probe powers of 50 nW are typically used with no observed effect on the loss rate or temperature of the trapped atoms.

After the valve is opened, 2×10^{12} Cr atoms in the fully stretched state $|J=3,m_J=+3\rangle$ and 4×10^{11} Mn atoms in the fully stretched state $|m_J=+5/2,m_I=+5/2\rangle$ are detected in the magnetic trap at peak densities of $4\times10^{13}\,\mathrm{cm}^{-3}$ and $3\times10^{12}\,\mathrm{cm}^{-3}$, respectively. The other isotopes of Cr, which are less naturally abundant, cannot be spectroscopically resolved under the current experimental conditions. We do detect other hyperfine states ($|m_J=+5/2,m_I=-5/2,\ldots,+3/2\rangle$) of Mn in the trap but with a factor of 5 or more lower yield.

We monitor the decay of the trapped sample to measure the interspecies inelastic collision rate (Fig. 2). By blocking one of the ablation beams and loading the trap with only one atomic species, we alternately monitor the trap loss due to Mn-Mn or Cr-Cr inelastic collisions. The decay of a single trapped species fits well to the expected functional form for two-body loss. At a temperature of 600 mK and trap depth of 3.5 T, the Mn-Mn and Cr-Cr inelastic rate constants are $\Gamma_{\mathrm{Mn,Mn}}=3.8(\pm0.2)\times10^{-13}\,\mathrm{cm}^3/\mathrm{s}$ and $\Gamma_{\mathrm{Cr,Cr}}=5.0\,(\pm0.5)\times10^{-14}\,\mathrm{cm}^3/\mathrm{s}$, respectively.

Mn and Cr are also loaded simultaneously so as to extract the Mn-Cr inelastic rate. The decays are fit to the appropriate rate equations:

$$\frac{d}{dt}n_{\mathrm{Mn}}(t)=-\Gamma_{\mathrm{Mn,Mn}}\int n_{\mathrm{Mn}}^2(r,t)d^3r-\Gamma_{\mathrm{Mn,Cr}}\int n_{\mathrm{Mn}}(r,t)n_{\mathrm{Cr}}(r,t)d^3r, \qquad (1)$$

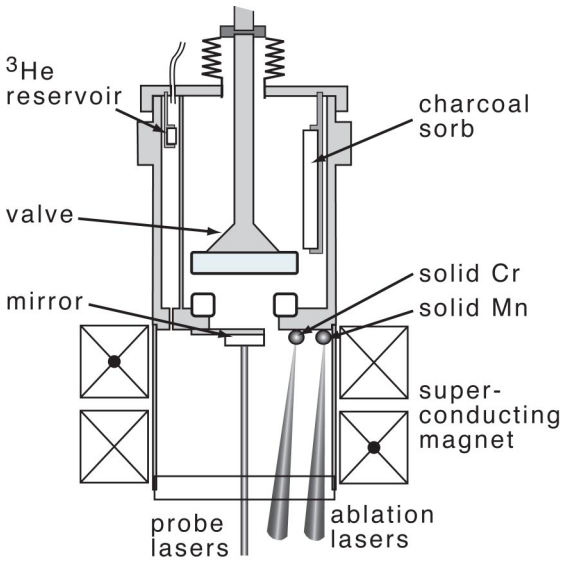

FIG. 1. Schematic of experimental apparatus. The cell is thermally linked to a ^{3}He refrigerator.

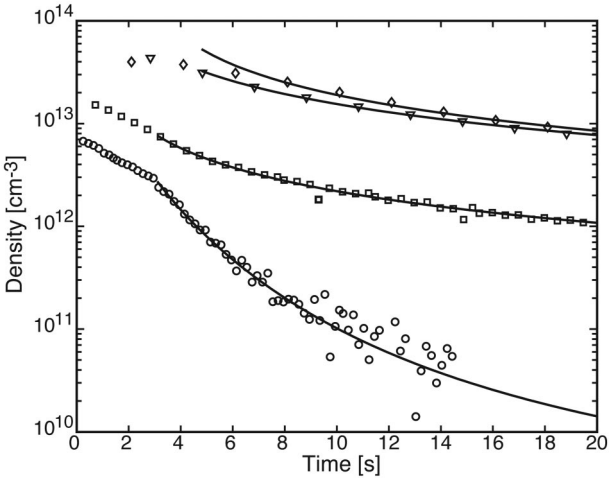

FIG. 2. Decay of the peak density of trapped Mn and Cr. Ablation pulse occurs at $t=0$. Valve opens at 3 s. Triangles: decay of Cr. Squares: decay of Mn. Diamonds: decay of Cr in the presence of Mn. Circles: decay of Mn in the presence of Cr. Solid lines: fits to expected loss model [Eqs.(1) and (2)].

$$\frac{d}{dt}n_{\mathrm{Cr}}(t) = -\Gamma_{\mathrm{Cr,Cr}}\int n_{\mathrm{Cr}}^2(r,t)d^3r - \Gamma_{\mathrm{Cr,Mn}}\int n_{\mathrm{Mn}}(r,t)n_{\mathrm{Cr}}(r,t)d^3r, \qquad (2)$$

where $n(r)$ is the density distribution in the trap of either Mn or Cr and Γ is the inelastic rate constant for Cr, Mn, or Mn-Cr. $\Gamma_{\mathrm{Mn,Cr}}$ is determined by numerically integrating Eq. (1) using the measured value of $\Gamma_{\mathrm{Mn,Mn}}$ and the measured decay of the trapped Cr as inputs. A least-squares fit of the measured Mn decay to the numerical solution of Eq. (1) yields a rate constant of $\Gamma_{\mathrm{Mn,Cr}}=1.5\,(\pm0.2)\times10^{-13}\,\mathrm{cm}^3/\mathrm{s}$ for Cr induced Mn trap loss, corresponding to a cross section of $\sigma_{\mathrm{Mn,Cr}}=1.4\,(\pm0.5)\times10^{-16}\,\mathrm{cm}^2$. Similarly, Eq. (2) can be numerically integrated to determine the rate constant for Mn induced Cr trap loss. However, because the density of Mn is an order of magnitude less than that of Cr, we are only able to place an upper limit of $\Gamma_{\mathrm{Cr,Mn}}\leqslant3\times10^{-13}\,\mathrm{cm}^3/\mathrm{s}$, consistent with $\Gamma_{\mathrm{Mn,Cr}}$, as expected. The dominant source of systematic error comes from determining the peak density from the measured absorption spectra.

The Mn-Cr inelastic rate is several orders of magnitude smaller than those measured in trapped alkali mixtures in the presence of magneto-optical trap (MOT) lasers ($\sim10^{-10}$ cm^3/s) [13,14]. In a MOT, light assisted collisions open up a number of additional decay channels including radiative escape and fine-structure changing collisions. In the absence of radiation fields, inelastic rates of $\leqslant10^{-14}\,\mathrm{cm}^3/\mathrm{s}$ were reported for bi-alkali mixtures in their fully stretched state [15]. Our measured Mn-Cr rate is similar to rates measured in single species systems with similar magnetic moments where dipolar relaxation is the dominant trap loss mechanism [16,17]. Taken as a whole, the measurement of magnetic dipolar two-body rates does not, as one might naively expect, scale as μ^4. The Cr-Cr inelastic rate measured here is much slower than either the Mn-Mn or Mn-Cr inelastic rate. The hyperfine structure of Mn may open additional inelastic channels. However, at our magnetic fields, these channels should be suppressed because the high-field Zeeman interaction is much larger than the hyperfine coupling. The variations though may be due to the fact that even at 0.6 K, differences in the details of the long-range part of the internuclear potential between the colliding pair play a significant role [18].

In conclusion, we have simultaneously trapped Mn and Cr in large numbers and measured the Mn-Cr interspecies inelastic rate constant. This demonstrates the general applicability of the buffer-gas cooling scheme to loading multiple species into a single magnetic trap, a crucial step in pursuing physics involving new binary mixtures.

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