Production of optically trapped $^{87}\text{RbCs}$ Feshbach molecules

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We report the production of $^{87}\text{RbCs}$ Feshbach molecules in a crossed-beam dipole trap. A mixture of $^{87}\text{Rb}$ and $^{133}\text{Cs}$ is cooled close to quantum degeneracy before an interspecies Feshbach resonance at 197 G is used to associate up to $\sim 5000$ molecules with a temperature of $\sim 300\text{nK}$. The molecules are confined in the dipole trap with a lifetime of 0.21(1) s, long enough for future experiments exploring optical transfer to the absolute ground state. We have measured the magnetic moment of the Feshbach molecules in a magnetic bias field range between 181 and 185 G to demonstrate the ability to control the character of the molecular state. In addition we have performed Feshbach spectroscopy in a field range from 0 to 1200 G and located three previously unobserved resonances at high magnetic fields.

I. INTRODUCTION

The production of ultracold polar molecules is of significant interest for a wide range of potential applications [1]. The permanent electric dipole moments of these molecules give rise to anisotropic, long-range dipole-dipole interactions which, when coupled with the precise control attainable for quantum systems, result in new prospects for research. Samples of ultracold molecules could prove useful for quantum simulation of condensed matter systems [2, 3], quantum computation [4, 5], precision measurements [6, 10] and controlled chemistry [11, 12].

Although other methods are making progress [13–16], currently the most successful technique for creating ultracold polar molecules relies on a two-step indirect method where the constituent atoms in a mixed-species quantum gas are associated into ground-state molecules [17]. First weakly bound molecules are made by magnetoassociation using an interspecies Feshbach resonance. Here an applied magnetic field is swept across the resonance, such that the energy of the separated atomic states is tuned adiabatically through an avoided crossing with the energy of a weakly bound molecular state [18]. The molecules are then optically transferred into their ro-vibrational ground state by stimulated Raman adiabatic passage (STIRAP) [19]. Although this method has been successfully applied in several systems [20–22], fermionic KRb is the only polar molecule that has so far been produced at high phase-space density [20]. However KRb is unstable as the exchange reaction $2\text{KRb} \rightarrow \text{K}_2 + \text{Rb}_2$ is exothermic [23]. An appealing alternative is to produce ground-state RbCs which is expected to be collisionally stable because both the exchange reaction and trimer formation reactions are endothermic [24].

Pilch et al. [25] have investigated Feshbach resonances in $^{87}\text{RbCs}$ at magnetic fields up to 300 G. Subsequently, Lercher et al. [26] achieved simultaneous $^{87}\text{Rb}$ and Cs BECs in separated dipole traps, while McCarron et al. [27] achieved a dual-species BEC in a single crossed dipole trap, where a phase separation of the condensates was observed [28]. Most recently, Takekoshi et al. [29] extended the Feshbach spectroscopy to 667 G and reported the production of $\sim 3000$ Feshbach molecules. They also combined information from the spectroscopy of the $X^1\Sigma^+$ and $\alpha^3\Sigma^-$ molecular states with the ultracold results to obtain a precise coupled-channels model of the interaction. The interaction potentials derived for $^{87}\text{RbCs}$ subsequently gave accurate predictions of resonance positions in $^{85}\text{RbCs}$ by mass scaling [30].

In this paper we report the production of up to $\sim 5000$ $^{87}\text{RbCs}$ Feshbach molecules from a nearly quantum-degenerate sample of $^{87}\text{Rb}$ and $^{133}\text{Cs}$. Molecules are trapped in an optical dipole trap with a lifetime of 0.21(1) s. We report measurements of the magnetic moment in a field range from 181 to 185 G to demonstrate the ability to control the character of the molecular state and to confirm the theoretical bound-state model. In the course of this work, we have also measured the interspecies Feshbach spectrum in a magnetic field range up to 1200 G, focussing on the previously unexplored magnetic field region above 600 G.

The structure of the paper is as follows. In Sec.II we present the results of our work on the interspecies scattering between $^{87}\text{Rb}$ and $^{133}\text{Cs}$. Calculations of the scattering length and the binding energy for weakly bound states are presented, together with our experimental observations of the Feshbach spectrum. In Sec.III we focus on the production of $^{87}\text{RbCs}$ Feshbach molecules and characterise the near-threshold bound-state spectrum through measurements of the magnetic moment of the molecules. In Sec.IV we conclude with an outlook on further experiments.
II. THE $^{87}$RbCs Feshbach Spectrum

A. Overview

The properties of a quantum-degenerate mixture are strongly influenced by both the intraspecies and the interspecies interactions [27, 31–33]. As such, full knowledge of all the scattering lengths is essential when devising a strategy to produce atomic mixtures with the high phase-space densities needed for magnetoassociation. In general, $^{87}$Rb is a desirable constituent of a mixed-species cold atom experiment since its scattering properties make cooling to quantum degeneracy possible over a wide magnetic field range and in several different internal states. The scattering properties of $^{133}$Cs are very different, exhibiting a large background scattering length and a rich spectrum of Feshbach resonances [34–37]. Efficient evaporation to Bose-Einstein condensation has been possible only in the absolute ground state ($f = 3, m_f = +3$) where inelastic two-body collisions cannot occur [27, 38, 39]. Even in this state, efficient evaporation is possible only for moderate scattering lengths in the vicinity of the zero-crossing of broad Feshbach resonances at 17.12, 556.26 and 880.90 G [37]. The intraspecies scattering lengths for $^{87}$Rb and $^{133}$Cs in their lowest hyperfine states are shown in Fig. 1(a). The $^{133}$Cs scattering curve is from the supplemental material of [37] and the $^{87}$Rb scattering curve was calculated using MOLSCAT [40] with the same methods outlined in [41], adjusted for the $^{87}$Rb parameters.

The interspecies s-wave scattering length in the lowest spin channel of $^{87}$Rb + $^{133}$Cs in the experimentally accessible field region is shown in the top panel of Fig. 1(b). The resonance positions and widths were calculated using MOLSCAT [40] as modified to handle collisions in magnetic fields [42], using the same basis set and methods as outlined in [29]. The parameters of the interatomic potentials were set by fitting the calculated Feshbach spectrum to experimental measurements in the field range of 0 to 600 G [29]. The background scattering length is $+651(±10)$ $a_0$ associated with the existence of a least-bound state with a binding energy of 110(2) kHz $\mu h$ [29]. The bound states immediately below threshold ($< 2$ GHz $\times h$) which are shown in the bottom panel of Fig. 1(b) were also obtained in the manner outlined in [29], using the BOUND package [43]. For the purposes of this study, all states with physical end-over-end rotation ($L > 0$) were excluded to make the figure and interpretation less cluttered. As in [29], bound states are labelled as $|n(f_{Rb}, f_{Cs})L(m_{Rb}, m_{Cs})\rangle$, where $n$ is the vibrational label for the particular hyperfine ($f_{Rb}, f_{Cs}$) manifold counting down from the least-bound state which has $n = -1$. One additional quantum number, $M_{tot}$, is omitted because in this study its value is always 4.

The high positive value of the background interspecies atomic scattering length determines the characteristics of the ultracold mixture. It leads to large three-body losses during the cooling process, which makes it difficult to produce a large sample of ultracold atoms at high phase-space densities suitable for magnetoassociation [26, 27, 44]. When quantum degeneracy is reached it leads to a phase separation of the two condensates [29]. Fortunately the interspecies scattering length shows many Feshbach resonances as well. The broad resonances due to s-wave states offer the possibility of improving the evaporation efficiency through tuning the interspecies collision cross section. In this context the two previously unobserved high-field resonances at 790 and 1115 G are interesting candidates. There are also many narrower resonances on which to explore magnetoassociation of molecules.

B. Experimental details

Details of our apparatus have been previously described in the context of studies on dual-species $^{87}$Rb–$^{133}$Cs condensates [27, 44] and Feshbach spectroscopy of an $^{85}$Rb and $^{133}$Cs mixture [30]. Initially cold atoms are collected in a two-species magneto-optical trap. The $^{87}$Rb and $^{133}$Cs atoms are then optically pumped into a two-species magneto-optical trap. The $^{87}$Rb atoms are then further cooled by forced RF evaporation while interspecies elastic collisions cool the $^{133}$Cs sympathetically. At 40 $\mu$K further efficient evaporation is prevented by Majorana losses [45] and the two species are transferred into a crossed-beam dipole trap formed using a 30 W single-frequency fibre laser at 1550 nm. The crossed trap consists of two independent beams, typically up to 6 W in power, focussed to waists of 70 $\mu$m. The beams intersect at an angle of 22°, at a position $\sim100$ $\mu$m below the field zero of the quadrupole trap. The dipole trap is loaded by simply reducing the magnetic field gradient of the quadrupole trap to 29 G/cm. Immediately following the transfer to the dipole trap, a 22 G bias field in the vertical direction is ramped on in 18 ms and RF adiabatic rapid passage is used to transfer the $^{87}$Rb and $^{133}$Cs atoms into the (1, +1) and (3, +3) states respectively [46]. The direction of the bias field is chosen such that the final high-field-seeking states of the atoms are levitated against gravity. The magnetic field gradient of 29 G/cm is chosen to be just below the 30.1 G/cm (30.5 G/cm) required to levitate $^{87}$Rb ($^{133}$Cs) at this magnetic field in order to aid evaporation from the trap. The near-identical ratios of magnetic moment to mass for this mixture ensure excellent spatial overlap of the two species in the trap. The dipole trap depth for $^{133}$Cs is $\sim 1.4$ times deeper than that for $^{87}$Rb due to the different polarizabilities at 1550 nm, making the trap well suited for sympathetic cooling of $^{133}$Cs via the direct evaporation of $^{87}$Rb by decreasing the power of the dipole trap beams. The large interspecies scattering length ensures that the two species remain in thermal equilibrium. To probe the mixture the trap and magnetic fields are switched off and resonant absorption images are captured for both species simultaneously using
a frame-transfer CCD camera \cite{17}.

Typically, $2.8(2) \times 10^6$ $^{87}$Rb atoms at a temperature of $9.6(1) \mu$K are confined in the dipole trap following the spin flip. The number of $^{133}$Cs atoms collected in the magneto-optical trap is actively controlled allowing the number ratio of $^{87}$Rb and $^{133}$Cs to be varied precisely. The depth of the trap for $^{87}$Rb ($^{133}$Cs) is then decreased from 76 $\mu$K (103 $\mu$K) to 3.1 $\mu$K (4.2 $\mu$K) over 1.25 seconds. The majority of the evaporation is performed at a bias field of 22 G where $^{133}$Cs can be cooled efficiently, though the final stages of cooling are performed at a magnetic field within the field range under investigation. Following the evaporation, a sample of typically $\sim 5 \times 10^5$ $^{87}$Rb atoms and $\sim 5 \times 10^4$ $^{133}$Cs atoms with a temperature between 200 and 700 nK remains confined in the dipole trap. Feshbach spectroscopy is then performed by exposing the ultracold atomic mixture to different magnetic bias fields and detecting the atom loss. The hold time at each field is adjusted to between 300 and 500 ms for different loss features to give the clearest signal. The significant imbalance in atom number between the two species increases the sensitivity of heteronuclear Feshbach spectroscopy; the $^{133}$Cs atoms act as a probe species immersed in a collisional bath of $^{87}$Rb atoms \cite{45}. The magnetic field is calibrated using microwave spectroscopy between Zeeman components of the different hyperfine states of $^{133}$Cs. These measurements reveal the long-term reproducibility of the field to be 0.1 G in the range.
TABLE I. Interspecies Feshbach resonances between $^{87}$Rb (1, +1) and $^{133}$Cs (3, +3) atoms. All five resonances resulting from $s$-wave states shown in the bound-state picture in Fig. 1 (b) are reported. In addition, we list a previously unobserved resonance due to a $d$-wave state at high magnetic field, together with measurements of the two resonances relevant for the magnetoassociation results presented in Sec. III. This work’s experimental errors shown are statistical standard errors resulting from fits as described in the text. Additional systematic uncertainties of 0.1 G and 0.5 G apply to resonance positions in the field ranges 0 to 400 G and 400 to 1200 G respectively. The results of previous measurements are listed for comparison. Theoretical widths correspond the difference in magnetic field between the pole and zero in the scattering length.

| $B_0$ (G) | $\Delta_{\text{exp}}$ (G) | Theory |
|-----------|----------------|--------|
| $\text{Experiment}$ | $\text{Previous work}$ | Quantum labels |
| $B_0$ (G) | $\Delta_{\text{exp}}$ (G) | $B_0$ (G) | $\Delta$ (G) |

| Resonances due to $s$-wave states |
| 279.03(1) | 0.11(1) | 279.12(5) | 0.09(3) | $\{-6(2,4)s(2,2)\}$ | 279.020 | 0.034 |
| 310.72(2) | 0.70(3) | 310.69(6) | 0.60(4) | $\{-6(2,4)s(1,3)\}$ | 310.714 | 0.586 |
| 352.7(2) | 2.9(5) | 352.65(34) | 2.70(47) | $\{-6(2,4)s(0,4)\}$ | 352.744 | 2.218 |
| 790.2(2) | 6.8(2) | $\{-5(2,3)s(2,2)\}$ | $\{-6(2,4)d(2,4)\}$ | 791.791 | 4.227 |
| 1115.2(2) | 10.0(6) | $\{-5(2,3)s(1,3)\}$ | $\{-6(2,4)d(1,2)\}$ | 1116.554 | 8.954 |

| Resonances due to $d$-wave states |
| 181.55(5) | – | 181.64(8) | 0.27(10) | $\{-6(2,4)d(2,4)\}$ | 181.631 | 0.183 |
| 197.10(3) | 0.1(1) | 197.06(5) | 0.09(1) | $\{-6(2,4)d(2,3)\}$ | 197.065 | 0.052 |
| 910.6(8) | – | $\{-5(2,3)d(1,2)\}$ | $\{-6(2,4)d(1,2)\}$ | 909.345 | 0.006 |

C. Results

The scattering length $a(B)$ passes through a pole at a Feshbach resonance, and in the vicinity of the resonance may be represented $a(B) = a_{\text{bg}}[1 - \Delta/(B - B_0)]$ [49], where $a_{\text{bg}}$ is the background scattering length, $B_0$ is the resonance position and $\Delta$ is the width. The three-body recombination rate scales approximately as $a^4$ [50]. Typical signatures of the resonances we observe in three-body loss spectra are shown in Fig. 2 for the two resonances due to $s$-wave states above 600 G. In both cases, the $^{133}$Cs atom number shows a significant drop followed by a pronounced peak as the resonance is crossed from low to high magnetic fields. The drop in atom number is due to the increase in the recombination rate near the pole of the resonance. Fitting a Lorentzian lineshape to the loss feature allows the resonance position $B_0$ to be assigned. Conversely, near the zero-crossing in the scattering length the three-body loss rate is reduced from the background value and the efficiency of sympathetic cooling improves, leading to an observed peak in the atom number. Fitting a Lorentzian lineshape to the peak in atom number allows an experimental width ($\Delta_{\text{exp}}$) to be determined for the resonance, defined to be the magnetic field difference between the minimum and maximum in the atom number.

In Table I we report measurements of all five resonances due to $s$-wave states below 1200 G resulting from the bound-state picture shown in Fig. 1 (b). For all of these resonances we can measure an experimental width ($\Delta_{\text{exp}}$). We can also calculate the width $\Delta$ from the positions of the pole and zero-crossing obtained from our coupled-channels model. Ongoing theoretical work [51] suggests that the width obtained from 3-body loss rates is systematically smaller than the 2-body width obtained from the pole and zero-crossing in the scattering length, particularly for narrow resonances, and the present results appear to support this conclusion. In addition, we list in Table I a previously unobserved resonance due to a $d$-wave state at high magnetic field, together with the two resonances relevant for the magnetoassociation results presented in Sec. III. Where available we also give the results of previous measurements [29] for comparison.

III. MAGNETOASSOCIATION OF $^{87}$RbCs FESHBACH MOLECULES

A. Overview

Feshbach molecules may be created by sweeping the applied magnetic field across a Feshbach resonance such that the energy of the separated atomic states is tuned adiabatically through an avoided crossing with the energy of a weakly bound molecular state [18]. Such a magnetoassociation sequence generally transfers a fraction of the atomic sample into the weakly bound molecular state responsible for the Feshbach resonance. The efficiency of the conversion from atoms to molecules is largely determined by the phase-space density of the atomic gas [52]. Further changes in the magnetic field allow navigation through the rich spectrum of near-threshold bound states (see the lower panel of Fig. 1 (b) for example), traversing...
the avoided crossings between molecular states either diabatically or adiabatically depending on the rate of change of the magnetic field. [53] The molecules may be separated from the atomic cloud by exploiting the difference in the magnetic moments of the molecules and the atoms; time of flight expansion in the presence of an applied magnetic field gradient leads to a Stern-Gerlach separation of the atoms and molecules [54]. In bosonic gases, a fast separation is essential to minimise inelastic collisions between the atoms and molecules which lead to loss, generally associated with the molecules being transferred to more deeply bound states. Following the separation, the molecular cloud can be detected by reversing the association sequence and imaging the atoms that result from the dissociation of the molecules [55, 56].

B. Magneto-association sequence

The bound-state spectrum relevant to magnetoassociation of $^{87}$RbCs molecules is illustrated in the lower panel of Fig.3(c). The creation and separation of molecules is complicated by the presence of the $|-1(1,3)s(1,3)\rangle$ bound state, which runs parallel to the atomic threshold at a binding energy of $110(2)$ kHz × $h$ [29]. This state leads to strong avoided crossings just below threshold as the more deeply bound molecular states responsible for the Feshbach resonances approach threshold. As a consequence sweeping across a Feshbach resonance from high to low field creates molecules in the near-threshold $|-1(1,3)s(1,3)\rangle$ state with a magnetic moment of $-1.3 \mu_B$. Crucially, the ratio of magnetic moment to mass for molecules in this state is almost identical to that for $^{87}$Rb in the $(1,+1)$ state and $^{133}$Cs in the $(3,+3)$ state. Consequently, in order for the Stern-Gerlach separation to work, the molecules must be transferred into a different state with a substantially different magnetic moment. We therefore associate the molecules on the Feshbach resonance arising from the $|-6(2,4)d(2,3)\rangle$ state at 197.10(3) G and then sweep the magnetic field to 181 G, adiabatically following the avoided crossing below the Feshbach resonance at 181.55(5) G and transferring the molecules via the weak-field-seeking $|-6(2,4)d(2,4)\rangle$ state into the high-field-seeking $|-2(1,3)d(0,3)\rangle$ state with a magnetic moment of $-0.9 \mu_B$. This path is illustrated in the lower panel of Fig.3(c) by the solid black line.

The timing of the magnetoassociation sequence is shown in Fig.1(a). An ultracold atomic mixture is produced by evaporation in the dipole trap at a bias field of 22 G. The magnetic field is then quickly increased to 212 G to avoid three-body losses induced by crossing several interspecies and intraspecies Feshbach resonances (see Fig.1). From here the field is decreased to 197.5 G, very close to the upper end of the resonance loss feature (see Fig.3(b)). After a hold time of 3.5 ms to allow the magnetic field to settle, the field is further decreased by ∼ 0.5 G in 2 ms. During this ramp, molecules in the least-bound state $|-1(1,3)s(1,3)\rangle$ are produced. In the current setup, the magnetic coils can levitate only high-field-seeking states against gravity. Therefore to separate the molecules and atoms we subsequently switch the field to 181 G in 0.1 ms, thereby transferring the molecules into $|-2(1,3)d(0,3)\rangle$ state. At the same time we switch off the optical dipole trap. After 7 ms time of flight, the atoms and molecules are completely separated. To detect the molecules, the magnetic field is ramped from 181 G to 199.7 G in 0.5 ms, reversing the association sequence and dissociating the molecular cloud. The magnetic bias field and gradient are then switched off and resonant absorption imaging is used to image both $^{87}$Rb and $^{133}$Cs onto a CCD camera.

C. Optimising the molecule production

The parameters of the ramp sequence reported above were all carefully optimised to maximise the number of molecules produced. The most sensitive parameter af-
racting the molecule production proved to be the composition of the initial ultracold atomic mixture. To explore this systematically, we varied the ratio of $^{87}$Rb and $^{133}$Cs by changing the number of $^{133}$Cs atoms loaded into the MOT. The results are shown in Fig. 4. The performance of the evaporation sequence is extremely sensitive to the initial number of $^{133}$Cs atoms loaded into the MOT. Figs. 4(a) and (b) show that, for a fixed evaporation ramp, a 50% change in the $^{133}$Cs atom number results in an order-of-magnitude change in the number and phase-space density of both $^{87}$Rb and $^{133}$Cs. This follows from our reliance on sympathetic cooling of $^{133}$Cs throughout the evaporation sequence. Concomitantly there is a sharp variation in the number of $^{87}$RbCs molecules produced, as shown in Fig. 4(c). The molecular conversion efficiency closely follows the geometric mean of the $^{87}$Rb and $^{133}$Cs phase-space densities, as shown in the inset of Fig. 4(c). At the peak of the plot we produce about 3000 molecules from an ultracold mixture containing $\sim 1 \times 10^5$ atoms of each species at a temperature of 0.1 $\mu$K. Changing the end point of the evaporation and adjusting the number of $^{133}$Cs atoms loaded into the MOT to maximise the average phase-space density leads to the production of slightly more molecules. Under optimum conditions we observe up to $\sim 5000$ molecules produced from a sample of $2 \times 10^5$ atoms of each species at a temperature of 0.3 $\mu$K. This represents a conversion efficiency of $\sim 2.5\%$.

D. Towards ground state molecules

For future experiments exploring the optical transfer of the molecules to the rovibrational ground state of the singlet potential, it is desirable to confine the Feshbach molecules in the optical dipole trap. This is achieved using a slightly different experimental routine shown by the dashed lines in Fig. 4. Now the power in the dipole trap remains on at a variable level and the magnetic field gradient is increased to 44 G/cm to levitate the molecules in the $|−2(1,3)d(0,3)\rangle$ state. This gradient over-levitates the atoms, resulting in a much reduced trap depth. Consequently all the unconverted atoms escape from the trap within 5 ms leaving a pure sample of molecules. To measure the lifetime of the molecules in the trap, we also reduce the power in each beam of the dipole trap to
100 mW. Under these conditions there is no trapping potential for the atoms, so that our lifetime measurements are not contaminated by residual atomic signals. The results are shown in Fig. 6. We observe a lifetime of the Feshbach molecules in the $|−2(1, 3)d(0, 3)\rangle$ state at 181 G held in the optical dipole trap. A magnetic field gradient of 44 G/cm is applied to levitate the molecules and the power in each beam of the dipole trap is 100 mW. Under these conditions there is no trapping potential for the atoms. The solid line shows an exponential fit to the results, which yields a lifetime of 0.21(1) s.

In summary we have produced ultracold samples of up to $\sim 5000$ $^{87}$RbCs Feshbach molecules using magnetoassociation on an interspecies Feshbach resonance. The molecules are formed from an atomic sample with a temperature of 300 nK and can be confined in an optical dipole trap with a lifetime of 0.21(1) s. We have demonstrated the control of the character of the molecules by adiabatic following of the bound-state spectrum using magnetic field ramps. The overall magnetoassociation efficiency observed in our experiment is in good agreement with results reported by Takekoshi et al. [29], despite

FIG. 6. Lifetime of $^{87}$RbCs molecules in the $|−2(1, 3)d(0, 3)\rangle$ state at 181 G held in the optical dipole trap. A magnetic field gradient of 44 G/cm is applied to levitate the molecules and the power in each beam of the dipole trap is 100 mW. Under these conditions there is no trapping potential for the atoms. The solid line shows an exponential fit to the results, which yields a lifetime of 0.21(1) s.

IV. CONCLUSION AND OUTLOOK

In summary we have produced ultracold samples of up to $\sim 5000$ $^{87}$RbCs Feshbach molecules using magnetoassociation on an interspecies Feshbach resonance. The molecules are formed from an atomic sample with a temperature of 300 nK and can be confined in an optical dipole trap with a lifetime of 0.21(1) s. We have demonstrated the control of the character of the molecules by adiabatic following of the bound-state spectrum using magnetic field ramps. The overall magnetoassociation efficiency observed in our experiment is in good agreement with results reported by Takekoshi et al. [29], despite
very different approaches used in producing the initial ultracold atomic mixture. In the course of this work, we have also detected several previously unobserved interspecies Feshbach resonances in the high magnetic field region. The positions of these resonances agree very well with the theoretical predictions, further supporting the quality of the fitted interspecies potential \(^2\).

These results represent a good starting point for exploring the optical transfer from the Feshbach state to the rovibrational singlet ground state using stimulated Raman adiabatic passage \(^1\). The relevant molecular spectroscopy for ground state transfer of \(^87\)RbCs has recently been reported by Debatin et al. \(^5\). We have constructed a suitable laser system in which the two lasers used in the optical transfer are frequency stabilised to a common ultra-low expansion optical resonator \(^6\) and are currently investigating one- and two-photon optical spectroscopy of the ultracold \(^87\)RbCs Feshbach molecules. The subsequent transfer to the ground state will realise an ultracold gas of stable polar molecules with numerous applications.

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\begin{figure}[h]
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\includegraphics[width=\textwidth]{fig7.png}
\caption{Magnetic moment of the \(^87\)RbCs molecules as a function of the magnetic bias field. The experimental points are determined by finding the magnetic field gradient at which the molecules are levitated. Note the measurements are restricted to magnetic moments in the high-field-seeking region due to the current coil geometry in the experiment. The solid line is the theoretical prediction for the molecular states following the magnetoassociation path shown in Fig.\[5\](c).}
\end{figure}
