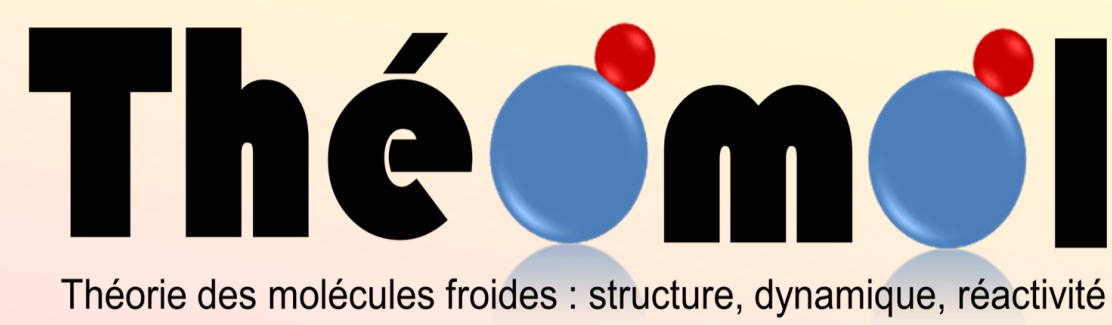


Optical Shielding of Destructive Chemical Reactions between Ultracold

Ground-State NaRb Molecules



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Introduction

Research focusing on the formation of ultracold atomic and molecular quantum gases is a continuously expanding field due to its envisioned applications such as quantum-controlled chemistry or quantum simulation. The aim of our theoretical work is to find ways to suppress inelastic or reactive processes between colliding particles in ultracold quantum gases [1]. We propose a method to suppress the chemical reactions between ultracold bosonic ground-state $^{23}\text{Na}^{87}\text{Rb}$ molecules based on optical shielding. By applying a laser with a frequency blue-detuned from the transition between the lowest rovibrational level of the electronic ground state $X^1\Sigma^+(v_X=0; j_X=0)$, and the long-lived excited level $b^3\Pi^0(v_b=0; j_b=1)$, the long-range dipole-dipole interaction between the colliding molecules can be engineered [2,3], leading to a dramatic suppression of reactive and photoinduced inelastic collisions, for both linear and circular laser polarizations. We demonstrate that the spontaneous emission from $b^3\Pi^0(v_b=0; j_b=1)$ does not deteriorate the shielding process. This opens the possibility for a strong increase of the lifetime of cold molecule traps and for an efficient evaporative cooling. We also anticipate that the proposed mechanism is valid for alkali-metal diatomics with sufficiently large dipole-dipole interactions.

Optical shielding scheme for ground state ultracold alkaline bimolecular collision

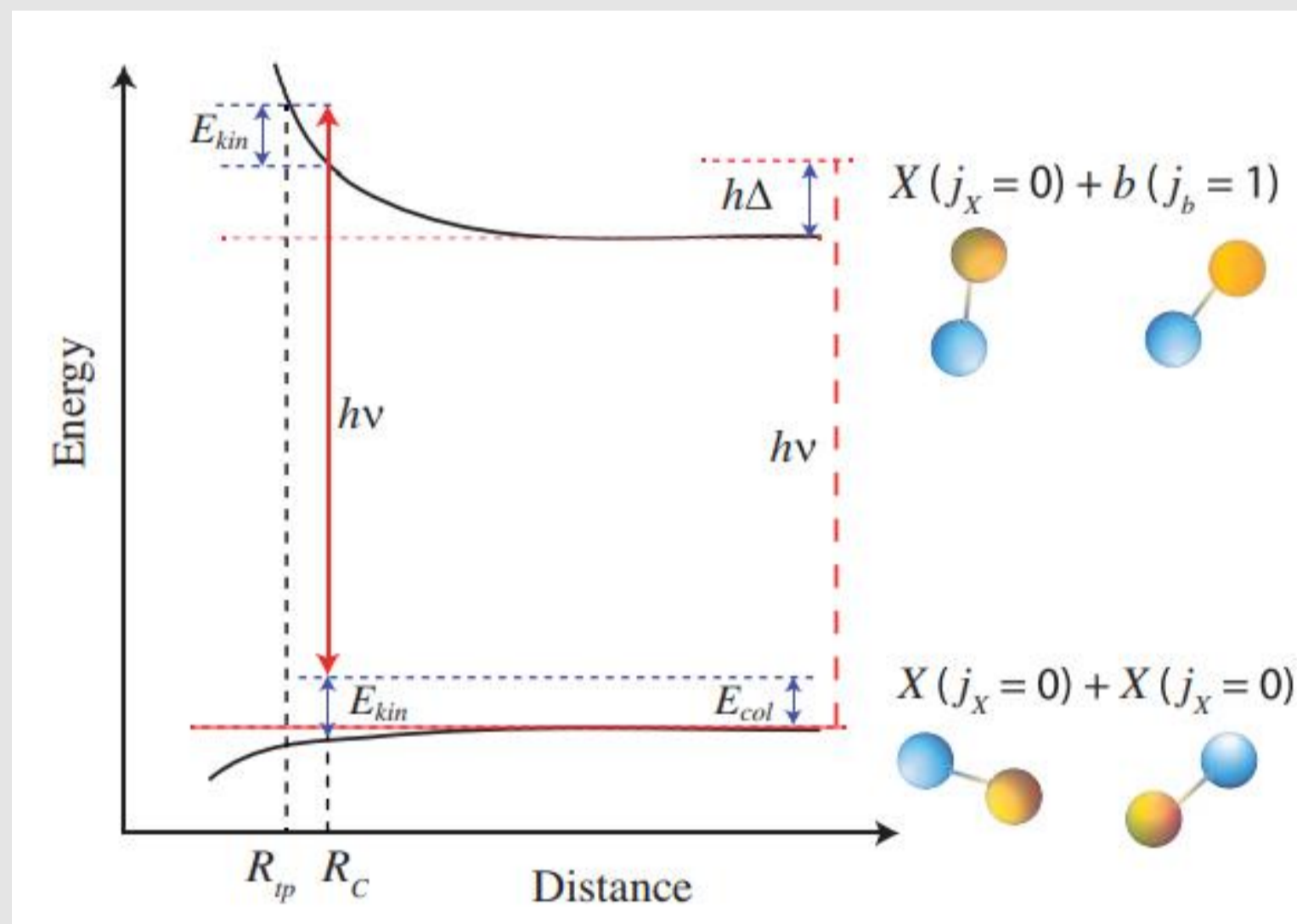


Fig. 1: Classical picture of the optical shielding. Two ground state molecules collide with energy E_{col} . At the Condon point R_C the pair absorbs a photon of energy $E=h\nu$ to reach a repulsive long-range potential-energy curve of a $[X(j_X=0) + b(j_b=1)]$ molecule interacting with an excited $[b(j_b=1)]$ molecule. $\nu=E/h$ is blue-detuned by $\Delta > 0$ from the $X(j_X=0) - b(j_b=1)$ transition frequency ν_{Xb} , i.e., $E=h\nu=h\nu_{Xb}+h\Delta$. R_{TP} is the classical turning point for the relative motion in the upper curve. The molecules are thus prevented from reaching the reactive zone. Stimulated emission in the excited complex also occurs if the field is strong enough (thus, the double-arrowed red line).

Conclusion and Outlook

- (1). By using the scheme we proposed, both polarized light can effectively suppress the inelastic collision rate with 3-4 magnitude order, thus increase the NaRb molecular sample lifetime. It is much different from microwave shielding of which only circularly polarized light works well [4].
- (2). The temperature dependence could be important at the region where effective evaporative cooling is already reached, hence a good news to experimentalists.
- (3). Our scheme can be applied in most of alkaline-metal bimolecules.

The molecule-molecule interaction potential

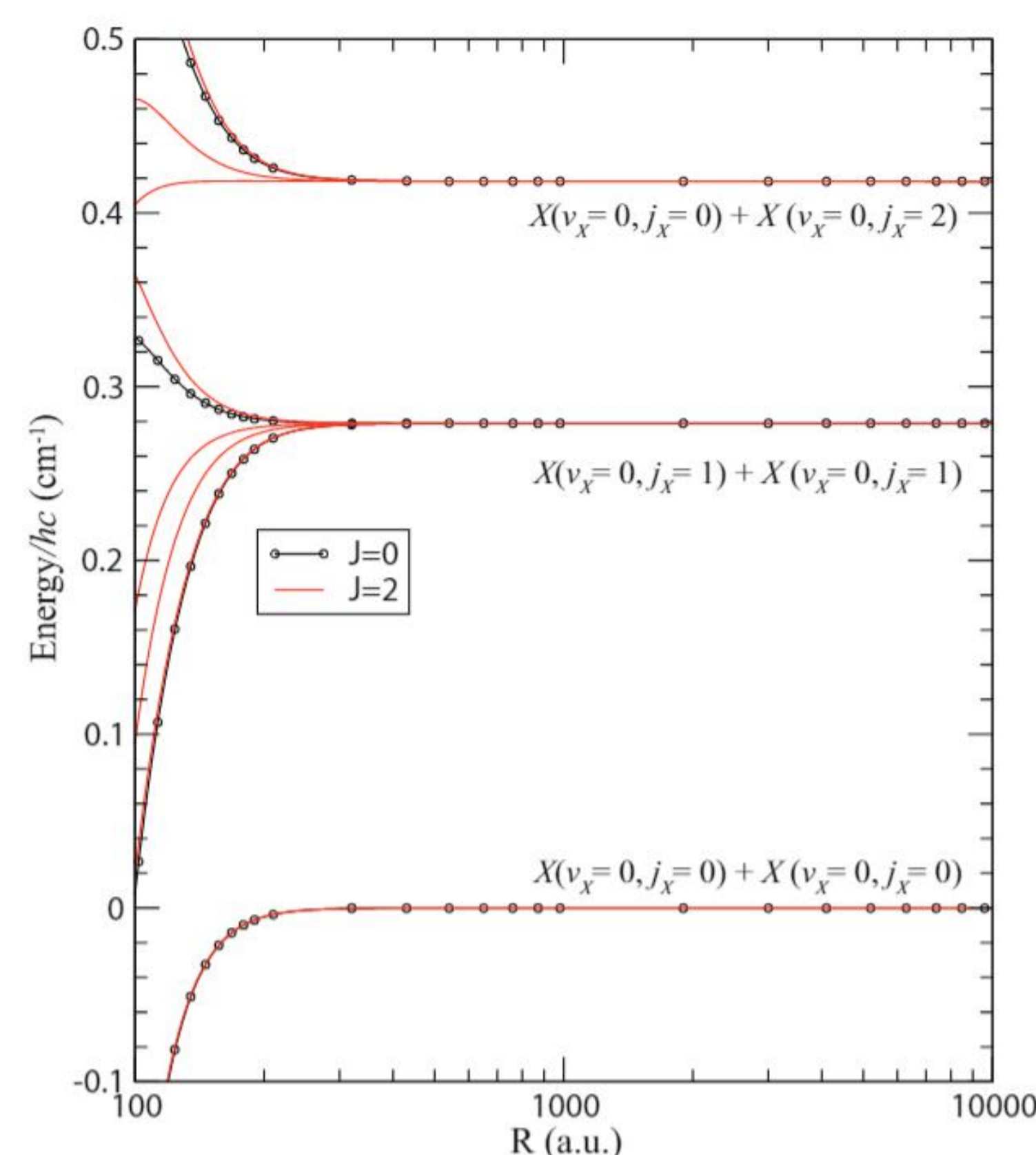


Fig 2: The adiabatic long-range potential-energy curves of even parity (without light interaction) correlated to the dissociation limits $^{23}\text{Na}^{87}\text{Rb}(j_X)+^{23}\text{Na}^{87}\text{Rb}(j_X)$, assuming that both molecules are in their lowest vibrational level. Only partial waves $l=0,2,4$ are included.

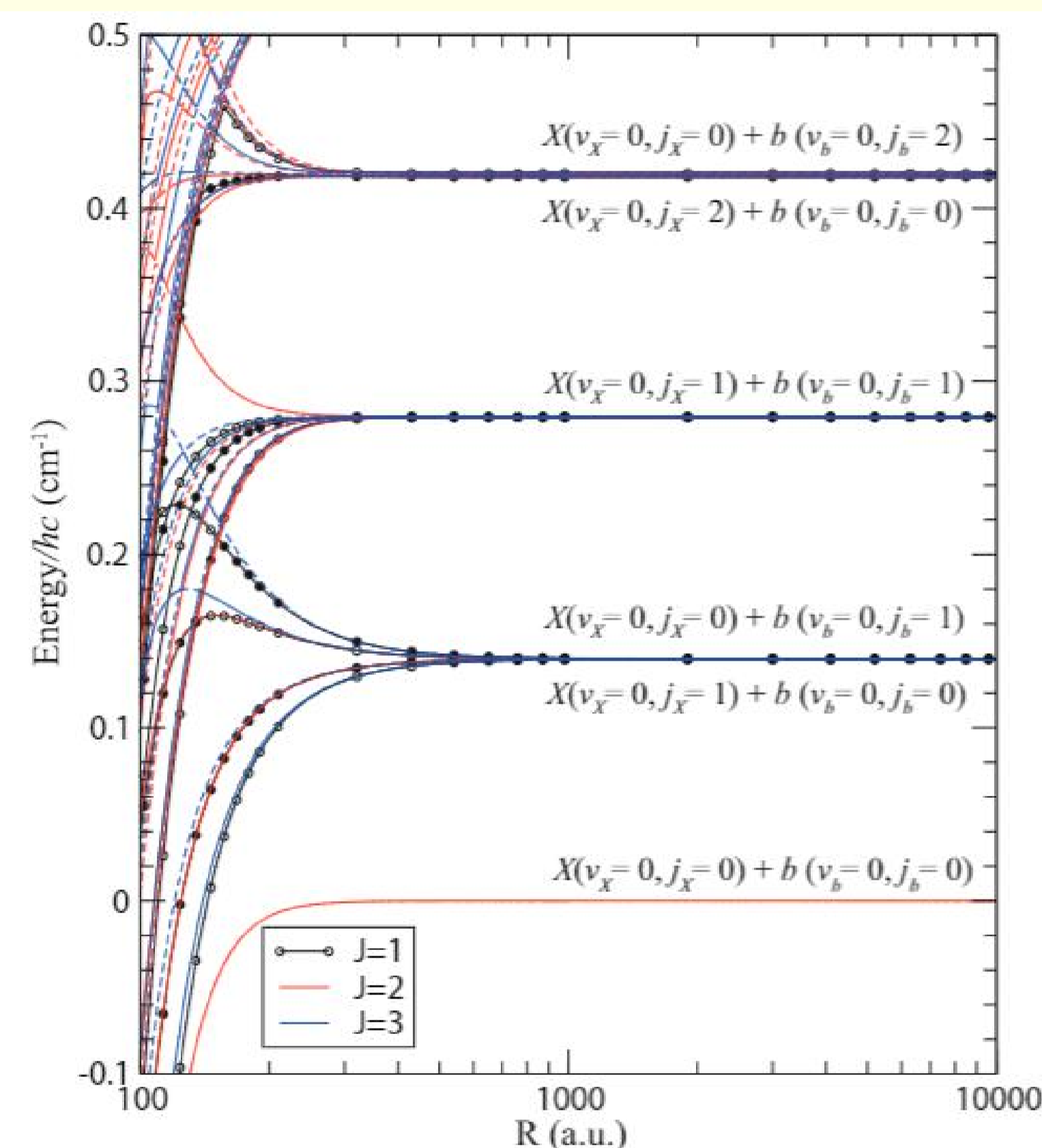


Fig 3: The adiabatic long-range potential-energy curves of odd parity (without light interaction) correlated to the dissociation limits $^{23}\text{Na}^{87}\text{Rb}(j_X)+^{23}\text{Na}^{87}\text{Rb}(j_b)$, assuming that both molecules are in their lowest vibrational level. Only partial waves $l=0,2,4$ are included.

The dressed-state potential in laser fields

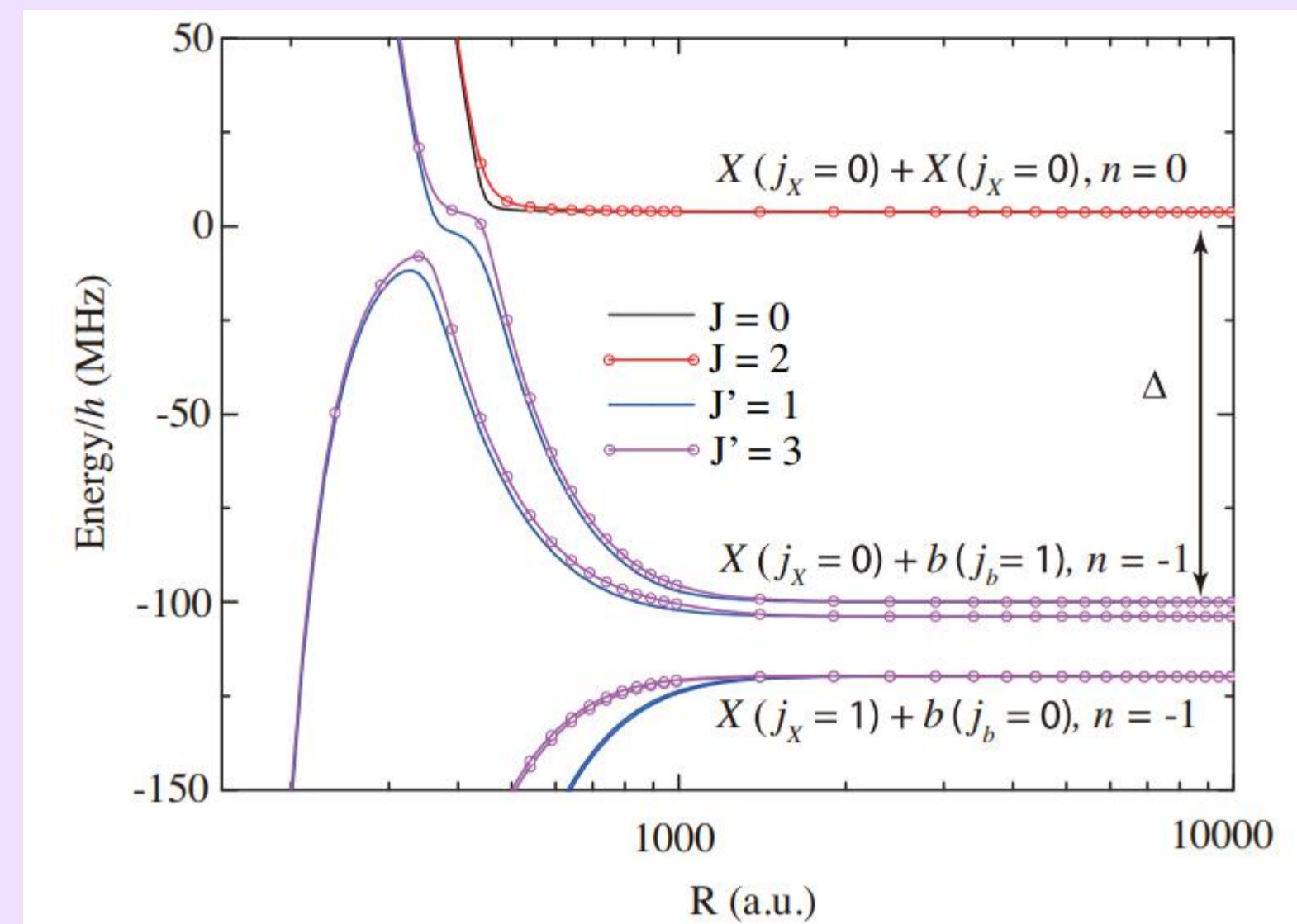


Fig.4: The dressed adiabatic long-range PECs of $^{23}\text{Na}^{87}\text{Rb}-^{23}\text{Na}^{87}\text{Rb}$ for $\Delta=100$ MHz and $\Omega=10$ MHz, in linear polarization. The Condon point (not displayed here) lies around $R_C=400$ a.u.. The curves are labeled with their dominant J character. Note that the asymptotic spacing between the $(j_X=0, j_X=0)$ and $(j_X=0, j_b=1)$ asymptotes is slightly larger (by 7.7 MHz) than Δ due to the presence of the stationary laser field [31]. For the same reason, the $(j_X=0, j_b=1)$ asymptote is split by 3.85 MHz as all the relevant states do not interact in the same way due to the laser.

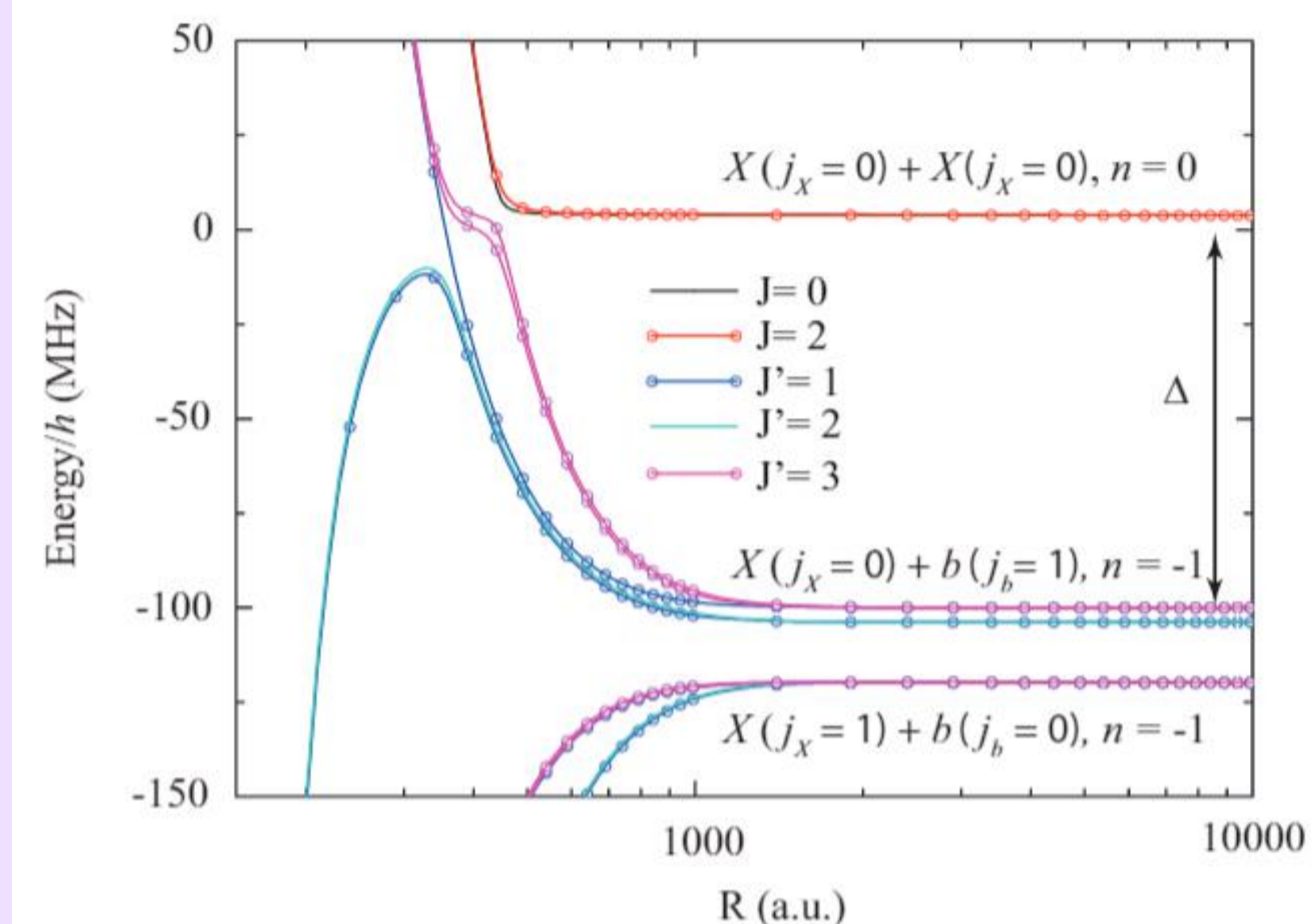


Fig. 5: The dressed adiabatic long-range potential-energy curves of $^{23}\text{Na}^{87}\text{Rb}-^{23}\text{Na}^{87}\text{Rb}$ for $\Delta=100$ MHz and $\Omega=10$ MHz in circularly-polarized light field. The Condon point (not displayed here) lies around $R_C=400$ a.u.. As in the linear polarization case, the asymptotic spacing between the $(j_X=0, j_X=0)$ and $(j_X=0, j_b=1)$ asymptotes is slightly larger than Δ due to the presence of the stationary laser field

Results and Discussion

Polarization dependence

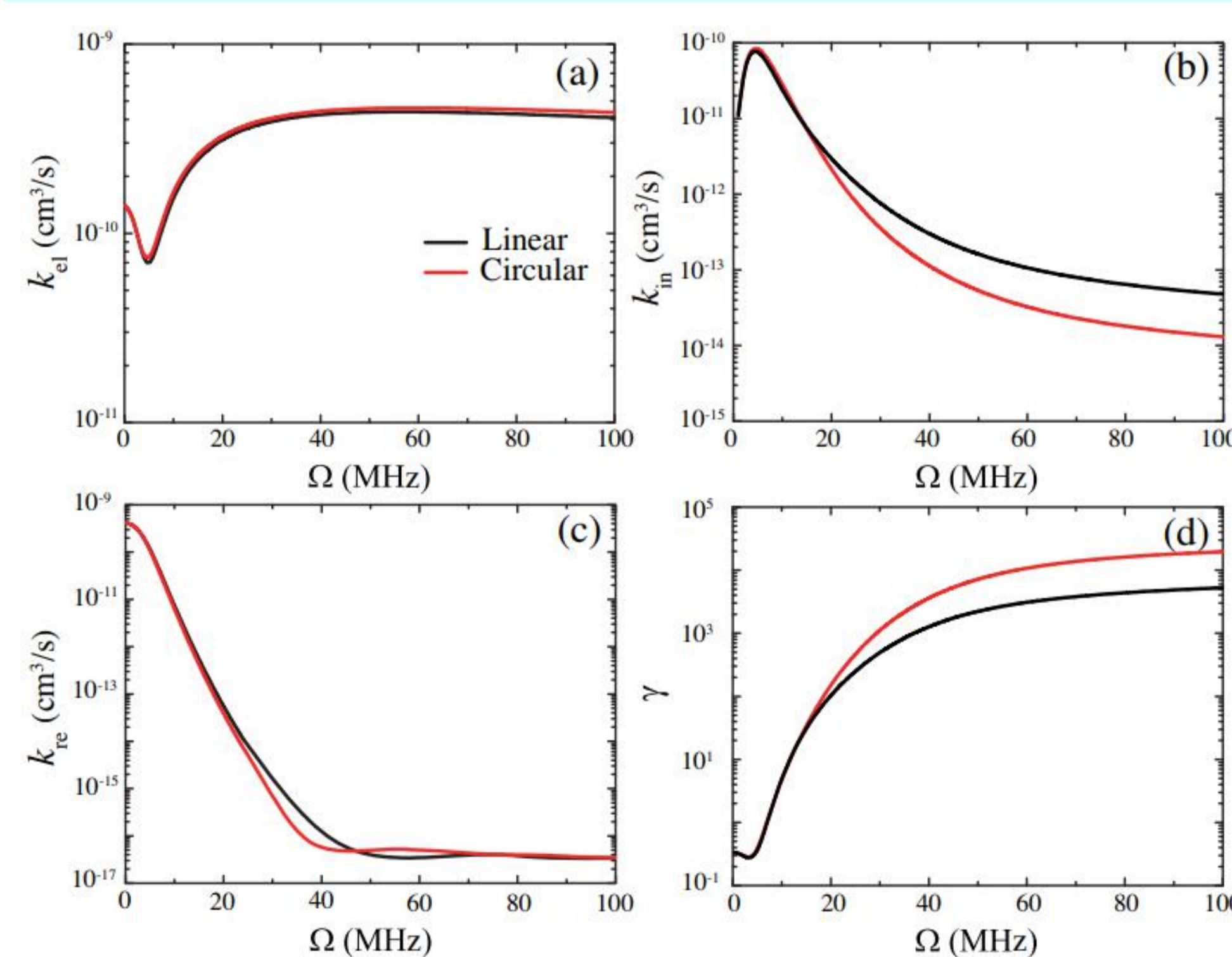


FIG. 6: Variation with the Rabi frequency Ω of the rate coefficients k_{el} , k_{in} , k_{re} for (a) elastic, (b) photoinduced inelastic, and (c) reactive collisions, respectively, and (d) of the shielding efficiency γ , for both linear and circular polarizations. The collision energy is $k_B \times 400$ nK and the laser detuning $\Delta=100$ MHz.

Temperature and detuning dependences

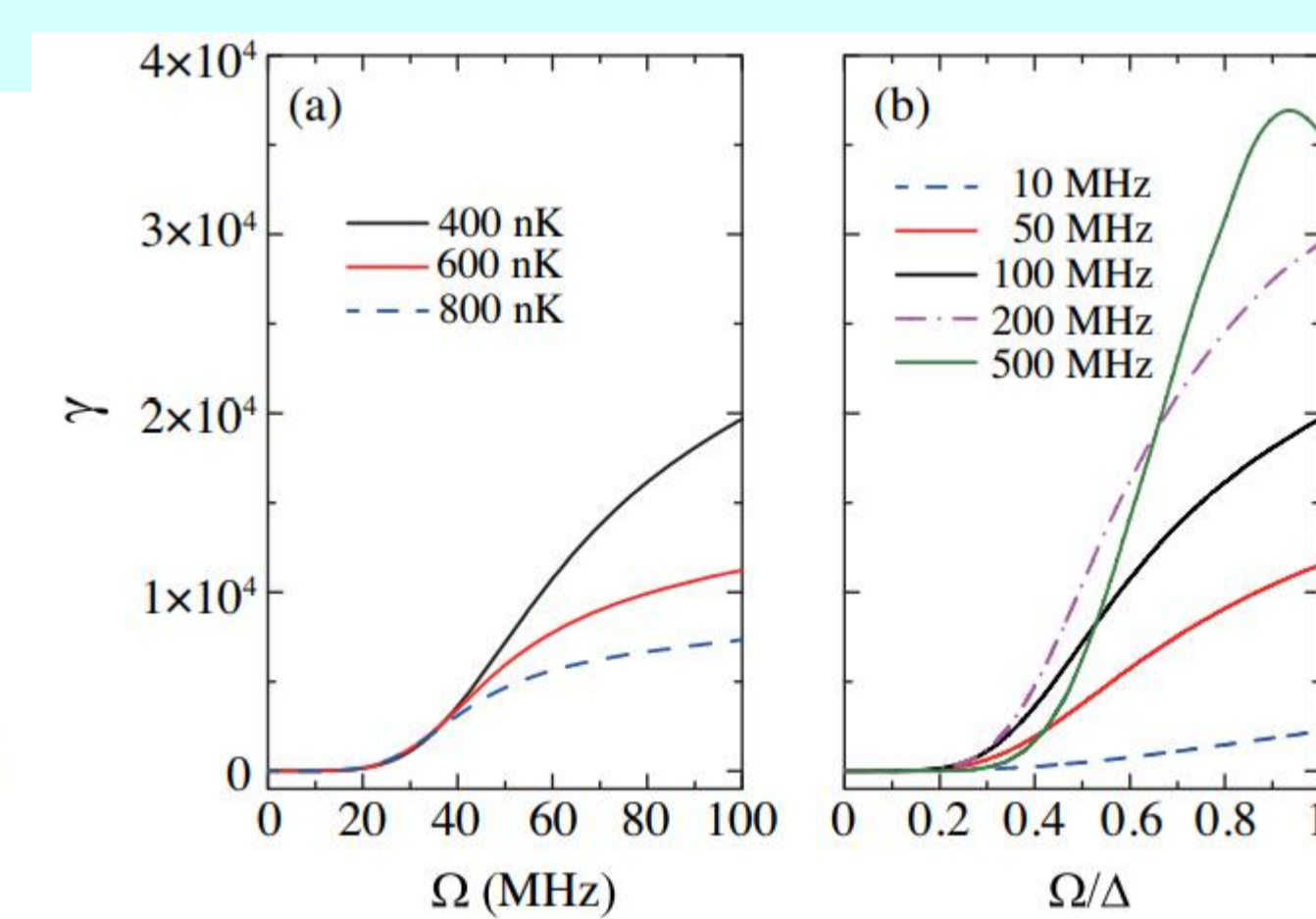


FIG. 7: Variation of γ in circularly polarized light (a) with Ω , at $\Delta=100$ MHz, and for $T=400, 600, 800$ nK, and (b) with the ratio $\Omega=\Delta$ (kept < 1), at $T=400$ nK for $\Delta=10, 50, 100, 200, 500$ MHz.

Possible applications in other systems

Species	$\Omega_{\gamma=1000}$ (MHz)	$I_{\gamma=1000}$ (W cm^{-2})
$^7\text{Li}^{39}\text{K}$	225.1	3294
$^7\text{Li}^{87}\text{Rb}$	53.8	35
$^7\text{Li}^{133}\text{Cs}$	36.1	14
$^{23}\text{Na}^{39}\text{K}$	92.8	265
$^{23}\text{Na}^{87}\text{Rb}$	29.3	6.3
$^{23}\text{Na}^{133}\text{Cs}$	24.5	2.0
$^{39}\text{K}^{133}\text{Cs}$	48.8	14
$^{87}\text{Rb}^{133}\text{Cs}$	101.2	53

TABLE I. Estimation of Ω values and corresponding laser intensities I to reach $\gamma=1000$, at 400 nK, with $\sigma \pm$ light and $\Delta=100$ MHz, for bosonic alkali-metal diatomics. The LiNa and KRb species are not listed as they do not have large enough DDI to allow such a large value of γ .

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