

Article

Lifetime Measurement of Cesium Atoms Using a Cold Rydberg Gas

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Abstract: The lifetimes of $nS_{1/2}$ and $nD_{5/2}$ ($n = 60\text{--}83$) cesium Rydberg states are measured accurately in a magneto-optical trap using the field ionization technique and analyzed with the existing theoretical model. The room temperature blackbody radiation (BBR) and interaction between Rydberg atoms can enhance the decay rate and reduce the spontaneous lifetime of the given Rydberg atom. The measured lifetime shows a good agreement with the calculation accounting a room temperature BBR at low enough Rydberg atomic density. The dependence of measured lifetime on atomic density shows that the collision and interaction between Rydberg atoms have a large effect on the lifetime at higher Rydberg atomic density. The scaling laws of $n^{2.55 \pm 0.02}$ for $nD_{5/2}$ state and $n^{2.30 \pm 0.01}$ for $nS_{1/2}$ state within $n = 60\text{--}83$ range are obtained and agreement with the model calculation with a relative deviation less than 3%.

Keywords: Rydberg atoms; lifetime; blackbody radiation



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1. Introduction

Rydberg state of alkali atom, the principal quantum number $n \gg 1$, has been extensively investigated due to its extraordinary properties. The attractiveness of Rydberg atom mainly arises from the properties of large size and transition dipole moment, strong interaction, and long radiative lifetime, and so on [1]. The lifetime of Rydberg atom scales as n^3 , for example, the calculated spontaneous radiative lifetime of the $70S_{1/2}$ Rydberg atom is 371.6 μs . However, the lifetime of Rydberg state is affected by the blackbody radiation and the strong interaction between Rydberg atoms scaling as n^{11} [2–4]. Therefore, accurate measurements of the lifetimes of Rydberg states are not only important to test theoretical calculations of the dipole matrix element and the oscillator strength but also for the determination of absolute cross section of collision and related phenomena such as population transfer due to blackbody radiation [1,5] and the Rydberg-atom based quantum information process and quantum simulations [6–9].

The lifetime of rubidium $|27D\rangle$ state [10] was firstly measured with the laser cooled rubidium atom [11,12] and then the measurement of $|nD\rangle$ Rydberg states for $26 < n < 45$ range was reported with measurement accuracy less than 3% [13,14]. The lifetime of cesium Rydberg $|nD_{5/2}\rangle$ state for $50 < n < 75$ range were measured in a 1064-nm far-off-resonance trap by the mean of measurements of photoionization rates [15]. The cesium $|nS\rangle$ and $|nD\rangle$ state for $30 < n < 40$ range were measured in a magneto-optical trap (MOT) by the field ionization technique [4,16]. In theory, Beterov et al. [5] calculated the spontaneous radiation lifetime and effective lifetime of alkali Rydberg atom with taking into account the blackbody radiation (BBR) in the range of $10 \leq n \leq 80$ employing the quasiclassical approximation.

In this work, we present an experimental measurement of the lifetime of cesium $|nS_{1/2}\rangle$ and $|nD_{5/2}\rangle$ Rydberg atoms ($n = 60\text{--}83$) with a MOT by the field ionization technique. The

effects of the room temperature BBR and atomic density on the Rydberg decay rate and further lifetime are investigated, which show that the blackbody radiation and strong interaction between Rydberg atoms can enhance the decay rate and modify the lifetime of the given Rydberg state. Finally, the scaling law of Rydberg lifetime is investigated and the experimental measurements agree well with the calculations of literature [5], the cross section of Rydberg interaction is extracted from the density dependence of the decay rate. Difference from Refs. [15,16], the n -range used here is $n = 60$ –83, and the agreement between the lifetime measurements and model calculations provides an evidence that the calculation of the effective lifetime accounting BBR in the Ref. [5] can be extend to $n = 83$.

2. Experimental Setup

Experiments are performed in a standard MOT by the laser cooling and trapping technology with a temperature of ~ 100 μ K and a density of $\sim 10^{10}$ cm^{-3} . The MOT density is measured with the shadow imaging technique. Figure 1a shows the schematic diagram of the experiments. Two-photon scheme, see Figure 1b, is employed to excite MOT atoms to Rydberg states. The first photon, 852 nm laser (Toptica DLpro), and the second photon, 510 nm laser (Toptica DLpro + Precilasers YFL-SHG-509-1.5), are counter propagated through the MOT center. The waists of the 852 nm and 510 nm lasers at MOT center are 80 and 40 μ m, respectively, which forms a cylindrical excitation volume. The frequency of the 852 nm laser is locked on the $|6S_{1/2}, F = 4\rangle(|g\rangle) \rightarrow |6P_{3/2}, F' = 5\rangle(|e\rangle)$ transition with a polarization spectroscopy, and then $\delta = 360$ MHz blue-detuned from the intermediate $|6P_{3/2}\rangle$ state by a double-passed acousto-optic modulator (AOM). The 510 nm laser is produced by frequency doubling of a 1020 nm laser with the frequency locked to an ultra-stable Fabry-Perot (F-P) cavity with a finesse of 15,000 employing Pound–Drever–Hall (PDH) method [17–20]. The frequency, monitored by a wavelength meter (HighFinesse-Angstrom WS-U), then is tuned to the nS/nD Rydberg transition by varying the radio-frequency signal applied to the electro-optic modulator (EOM) that is used to lock the laser to the F-P cavity.

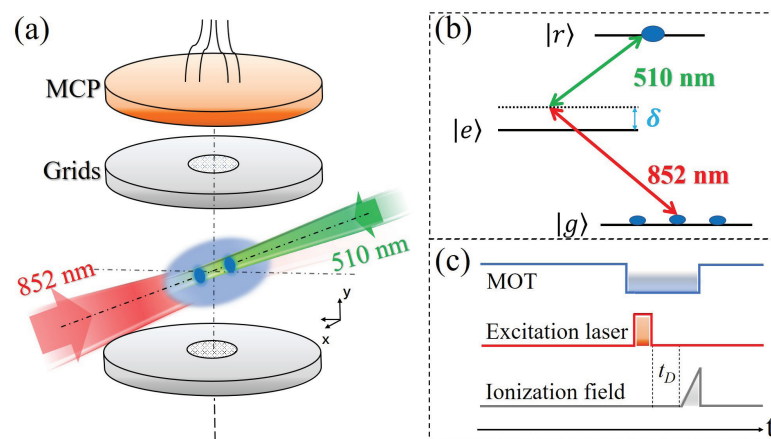


Figure 1. (Color online) (a) The schematic diagram of the experiment. Cesium atoms are trapped in the MOT center and excited to the Rydberg state employing a two-photon excitation. The first-photon 852 nm and the second-photon 510 nm lasers are counter propagated and overlapped at the MOT center. The excited Rydberg atoms are ionized with a ramped electric field and detected with a microchannel plate (MCP) detector. Three pairs of grids are placed on either side of the MOT (the other two pairs do not show here) that can be used to apply potential for ionizing Rydberg atom or compensating a stray electric field. (b) The level diagram of two-photon excitation of Rydberg state. The first photon drives the lower transition $|g\rangle \rightarrow |e\rangle$, while the second photon couples the up transition $|e\rangle \rightarrow |r\rangle$. The single photon detuning from the intermediate state is $\delta = 360$ MHz. (c) A timing diagram for the excitation and the detection of Rydberg atoms. After Rydberg excitation and a variable delay time t_D , a ramp electric field with 3 μ s rising time is applied for ionizing Rydberg atoms.

There are three pairs of grids placed either side of the MOT in three directions, (only one pair of grids in the y -direction shown in Figure 1a), that are used to apply the potential for compensating the stray field and ionization of the Rydberg atoms. After compensating, the related stray field around the MOT is expected to be less than 30 mVcm^{-1} measured with the Stark spectroscopy of the $70D_{5/2}$ state [21]. After the Rydberg excitation, we apply a ramped electric field of $3\text{-}\mu\text{s}$ rise time to one grid to ionize Rydberg atoms and drive resultant ions onto a microchannel plate (MCP) detector located behind one of the grids. To obtain the evolution of Rydberg populations, we apply a variable delay time t_D before the ramp ionization field, see the timing of Figure 1c. The Rydberg ions are analyzed by a boxcar integrator (SRS-250) and recorded with a computer. Before the lifetime measurement, we calibrate the MCP ions detection system with two shadow images taken before and after the Rydberg excitation. The Rydberg number and the gain factor, G , of our MCP detection are extracted from the difference of two shadow images. Then the number of the Rydberg excitation N_R can be obtained with the formula $N_R = \frac{V_{\text{signal}} \times t_{\text{gate}} \times S_{\text{sensitivity}}}{G}$, with the V_{signal} the intensity of the measured signal, and t_{gate} and $S_{\text{sensitivity}}$ the boxcar gate width and the sensitivity, respectively.

3. Experimental Method and Results

3.1. Lifetime Measurement

In Figure 2, we present the measured population of $|65D_{5/2}\rangle$ Rydberg state as a function of the delay time t_D , from which the lifetime for a given Rydberg state is obtained. The extracted lifetime of $|65D_{5/2}\rangle$ state is $94.1 \pm 2.5 \text{ }\mu\text{s}$ and the related decay rate is $10.63 \pm 0.29 \text{ kHz}$. The inset of Figure 2 displays the Rydberg spectrum when we scan the second excitation laser frequency for the delay time $\tau_D = 5 \text{ }\mu\text{s}$.

The radiative lifetime of an atom at $T = 0 \text{ K}$ mainly comes from the spontaneous decay rate, which is the inverse of the Einstein A-coefficient. For the nL Rydberg state and transition $nL \rightarrow n'L'$ (L and L' denote the angular quantum number), the Einstein A-coefficient is written as [1]

$$A(nL \rightarrow n'L') = \frac{4\omega_{nn'}^3}{3c^3} \frac{L_{\max}}{2L+1} R^2(nL \rightarrow n'L') \quad (1)$$

where $R(nL \rightarrow n'L')$ is the Radial transition matrix element, $L_{\max}$ is the maximum of L and L' , and $\omega_{nn'}$ is the transition frequency between nL and $n'L'$, respectively. Considering all possible transitions of $nL \rightarrow n'L'$, the spontaneous decay rate of nL state, Γ_{sp} , is taken as

$$\Gamma_{sp} = \sum_{E_{nL} > E_{n'L'}} A(nL \rightarrow n'L') \quad (2)$$

The radiation lifetime τ_{sp} of the given nL state can be obtained by $\tau_{sp} = 1/\Gamma_{sp}$. For $|65D_{5/2}\rangle$ Rydberg state, the calculated spontaneous radiation decay rate is $\Gamma_{sp} = 6.27 \text{ kHz}$ and the related lifetime is $\tau_{sp} = 159.4 \text{ }\mu\text{s}$.

The measured lifetime of $|65D_{5/2}\rangle$ state, shown in Figure 2, $\tau_{exp} = 94.1 \pm 2.5 \text{ }\mu\text{s}$, is much less than the calculated spontaneous lifetime $\tau_{sp} = 159.4 \text{ }\mu\text{s}$. We attribute this dramatically decrease of the lifetime to two reasons. Firstly, at room temperature $T = 300 \text{ K}$, BBR photons of low-frequency microwave (MW) fields can provide successive energies to couple adjacent Rydberg states due to the Rydberg energy difference within the MW field range. The high number of MW photons per mode in the BBR field results in that the decay of a single Rydberg atom is orders of magnitude faster than that of $T = 0 \text{ K}$. Secondly, the interaction between Rydberg atoms will increase the collision loss rate of the given Rydberg state, thereby accelerating the decay of Rydberg state and decreasing its lifetime.

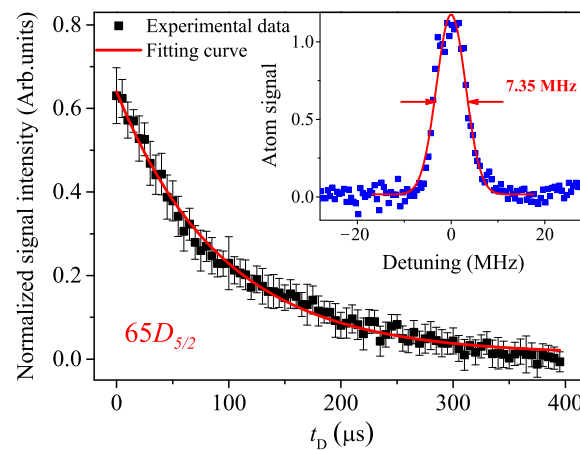


Figure 2. (Color online) Normalized population of the $|65D_{5/2}\rangle$ state as a function of the delay time t_D . Samples are the averaged results of 100 measurements and the red line displays the fitting of the exponential function. The extracted lifetime is $94.1 \pm 2.5 \mu$ s. The inset is the measured spectrum when we scan the second excitation laser frequency for the delay time $t_D = 5 \mu$ s, the linewidth of 7.35 MHz is obtained by Lorentz fitting shown with the red line.

3.2. Blackbody Radiation Induced Decay

In this section, we consider the effect of the BBR on the decay rate of Rydberg state. As we know that the room temperature BBR has a negligible effect for the ground atom, but has a strong effect for electronically high-lying Rydberg states and enhance the decay rate of Rydberg states [22–25]. Taking into account the BBR effect, the effective radiation decay rate of Rydberg atoms $\Gamma_{eff}(T)$ can be written as

$$\Gamma_{eff}(T) = \Gamma_{sp} + \Gamma_{BBR}(T) \quad (3)$$

with $\Gamma_{BBR}(T)$ the decay rate due to blackbody radiation at T . Therefore, the corresponding lifetime can be written as

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{sp}} + \frac{1}{\tau_{BBR}} \quad (4)$$

where τ_{BBR} is blackbody radiation lifetime of Rydberg atom. The spontaneous radiation rate Γ_{sp} and the related lifetime τ_{sp} for the give Rydberg state can be calculated with Equations (1) and (2). Using the Coulomb approximation method, Beterov et al. [5] calculates the BBR induced decay rate Γ_{BBR} at T for $10 \leq n \leq 80$ range. Decay rate due to BBR, Γ_{BBR} , can be written as [5]

$$\Gamma_{BBR} = \frac{A}{n_{eff}^D} \frac{2.14 \times 10^{10}}{\exp(\frac{315,780B}{n_{eff}^C T}) - 1} (\text{s}^{-1}) \quad (5)$$

where A, B, C and D are fitting parameters obtained from the fit of the numerical results based on a quasi-classical calculation [5] and corresponding values for Cs are given in Table 1, $n_{eff} = n - \delta_L$ is the effective quantum number (δ_L is quantum defect). At room temperature of 300 K, the calculated decay rate due to BBR is $\Gamma_{BBR} = 4.35$ kHz and the related lifetime is $\tau_{BBR} = 229.9 \mu$ s for $|65D_{5/2}\rangle$ Rydberg state. The corresponding effective lifetime, $\tau_{eff} = 94.1 \mu$ s, is consistent with the experimental result of $\tau_{exp} = 94.1 \pm 2.5 \mu$ s.

Table 1. Value of parameters A, B, C , and D of Cs in Equation (5).

State	A	B	C	D
$S_{1/2}$	0.123	0.231	2.517	4.375
$D_{5/2}$	0.036	0.073	1.770	3.636

3.3. Interaction Induced Decay

Due to the large orbital radius ($\sim n^2$), Rydberg atoms have a large collision cross-section with the ground atom and the Rydberg atom, which modify the decay rate and shorten the lifetime of the Rydberg atom. Moreover, the strong van der Waals interaction ($\sim n^{11}$) between Rydberg atoms will also affect the decay rate and lifetime of Rydberg atoms. In order to investigate the effect of the interaction between Rydberg atoms on the lifetime of Rydberg atoms, we do a series of measurements like as in Figure 2 but for different Rydberg densities by changing the power of the second excitation laser. Figure 3 shows the measurement of the lifetime (Figure 3a) and the decay rate (Figure 3b) as a function of the Rydberg atomic density for the $|60D_{5/2}\rangle$ state. It is found that the measured lifetime τ_{exp} decreases when the Rydberg density increases. For example, when the Rydberg atomic density $\rho = 5.71 \times 10^9 \text{ cm}^{-3}$, the measured lifetime is $30.3 \mu\text{s}$, two times less than the calculation of $\tau_{eff} = 76.3 \mu\text{s}$ by the Equation (4), as shown by the black arrow. The measured lifetime increases as the Rydberg density decreases, and up to $75.2 \mu\text{s}$ when Rydberg density $\rho = 2.57 \times 10^9 \text{ cm}^{-3}$, as shown in the blue oval of Figure 3a. It is noted, from Figure 3a, that the lifetime does not further increase even we decrease the Rydberg density further, which means that when the Rydberg density is smaller than some value, ρ_0 , ($\rho_0 = 2.3 \times 10^9 \text{ cm}^{-3}$ for the $|60D_{5/2}\rangle$ state), the interaction collision between Rydberg atoms has a negligible effect for lifetime measurements, and measured lifetime approaches the calculation of τ_{eff} . The dependence of lifetime on the Rydberg atomic density can be attributed to the collision interaction induced decay; also, see the measured decay rates of Figure 3b.

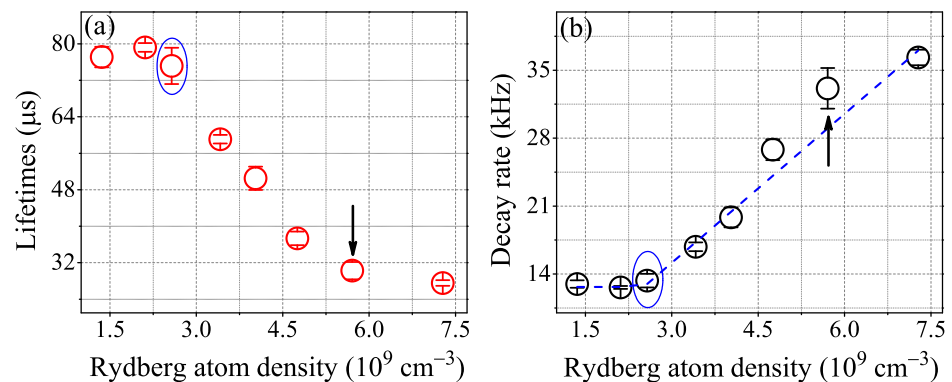


Figure 3. (Color online) Measured lifetimes (a) and decay rate (b) of the $|60D_{5/2}\rangle$ state as a function of the Rydberg atomic density. The dashed line in (b) is the fitting of Equation (6), from which the collision cross-section $\sigma_n = (5.11 \pm 0.36) \times 10^{-9} \text{ cm}^2$ is obtained. Blue ovals mark the measured lifetime (a) and decay rate (b) for the atomic density of $\rho = 2.57 \times 10^9 \text{ cm}^{-3}$, and black arrows sign the measured data for the density of $\rho = 5.71 \times 10^9 \text{ cm}^{-3}$.

In order to explain the behavior of Figure 3, we define the total decay rate, $\Gamma_{tol} = \Gamma_{sp} + \Gamma_{BBR}(T) + \sigma_n \nu \rho$, where σ_n is the cross section, ν is a velocity of the atom, and ρ is the Rydberg atomic density, respectively. For the case of $\rho \geq \rho_0$, the total decay rate linearly increases with the atomic density, but for the case of $\rho < \rho_0$, the total decay rate does not change and approaches to the content, $\Gamma_{eff}(T) = \Gamma_{sp} + \Gamma_{BBR}(T)$. Therefore, the Γ_{tol} is written as

$$\begin{cases} \Gamma_{tol} = \Gamma_{eff}(T) + \sigma_n \nu \rho & (\rho \geq \rho_0) \\ \Gamma_{tol} = \Gamma_{eff}(T) & (\rho < \rho_0) \end{cases} \quad (6a)$$

$$\begin{cases} \Gamma_{tol} = \Gamma_{eff}(T) + \sigma_n \nu \rho & (\rho \geq \rho_0) \\ \Gamma_{tol} = \Gamma_{eff}(T) & (\rho < \rho_0) \end{cases} \quad (6b)$$

For the $60|D_{5/2}\rangle$ state of the Figure 3, $\rho_0 \sim 2.3 \times 10^9 \text{ cm}^{-3}$. It is noted that the ρ_0 depends on the n used. The larger the n is, and the smaller ρ_0 is.

For obtaining the interaction cross-section, σ_n , we use the Equation (6) to fit the measured decay rates of Figure 3b, as shown with the blue dashed line of Figure 3b. The collision cross-section for $|60D_{5/2}\rangle$ $\sigma_n = (5.11 \pm 0.36) \times 10^{-9} \text{ cm}^2$ is extracted from the

fitting curve, which is close to a geometric cross section of $\pi r_{60D}^2 \approx 2.12 \times 10^{-9} \text{ cm}^2$. Further, we can obtain the Γ_{eff} ($T = 300 \text{ K}$) = $12.67 \pm 0.23 \text{ kHz}$, which agree with the calculated value 13.11 kHz by Equation (3).

From Figure 3a, we can see that measured lifetime decreases with the atomic density and that the lifetime approaches to the calculated effective lifetime τ_{eff} when the atomic density is less than $2.3 \times 10^9 \text{ cm}^{-3}$, corresponded interaction between Rydberg atoms being less than the spectral linewidth, where the interaction collision-induced decay has a negligible effect on the lifetime measurement of the give Rydberg state. In the measurement below, we use smaller excitation laser power and narrower excitation duration to keep low enough Rydberg atomic density, such that the influence of interaction between atoms on lifetime measurement can be neglected. Furthermore, it is worth to note that the MOT density or ground-atomic density has a tiny effect on the lifetime measurement of Rydberg state, which is verified by changing the repumping laser power and by the ref. [26].

3.4. N Dependence of Lifetime

We investigate the n scaling law of lifetime in this section. We measure the lifetime of Rydberg atoms with different principal quantum numbers $n = 60\text{--}83$ by changing the second laser frequency. In the Table 2 and Figure 4, we present the measurements and calculations of Rydberg lifetimes for $|nS_{1/2}\rangle$ (Figure 4a) and $|nD_{5/2}\rangle$ (Figure 4b) states. The measured data are the average of five independent measurements and the error bars display the standard error. We see that the measured lifetimes, τ_{exp} , agree well with the calculations, τ_{eff} , which shows that the influence of blackbody radiation at the room temperature is dominant, while the interaction induced decay has a negligible effect at the condition of the low Rydberg density. For comparison, we also display the calculations of spontaneous radiation lifetime τ_{sp} (blue stars), and BBR lifetime τ_{BBR} (pink triangles). Both the spontaneous radiation lifetime and BBR lifetime display increase with principal quantum number n . From Figure 4, it is found that the spontaneous lifetime is larger than the BBR lifetime at 300 K for $|nS_{1/2}\rangle$ Rydberg states, but less than BBR lifetime for $|nD_{5/2}\rangle$ states. This phenomenon is attributed to the fact that nS and nD states have different quantum defects and energy level structures that lead to the different radial matrix elements, as shown with the Equation (1). For both nS and nD states, the room temperature BBR will enhance the decay of the Rydberg atom and shorten the lifetime.

Table 2. Measurements of the lifetime τ_{exp} and calculations of spontaneous lifetimes τ_{sp} , blackbody radiation lifetimes τ_{BBR} and effective lifetimes τ_{eff} (in μs) of $|nS_{1/2}\rangle$ and $|nD_{5/2}\rangle$ Rydberg states, error bar displays the standard error of five independent measurements.

n	$S_{1/2}$				$D_{5/2}$			
	τ_{sp}	τ_{BBR}	τ_{eff}	τ_{exp}	τ_{sp}	τ_{BBR}	τ_{eff}	τ_{exp}
60	226.9	164.1	95.2	95.4 ± 2.7	124.2	197.6	76.3	75.7 ± 0.7
63	265.4	180.7	107.5	107.4 ± 2.4	144.7	216.7	86.7	85.3 ± 0.3
65	293.3	192.2	116.1	115.7 ± 1.8	159.4	229.9	94.1	94.6 ± 2.4
67	323.1	204.0	125.1	124.4 ± 1.8	175.2	243.5	101.9	102.0 ± 6.3
70	371.6	222.4	139.1	138.6 ± 2.4	200.7	264.5	114.1	115.4 ± 2.2
73	424.6	241.4	153.9	153.5 ± 4.2	228.6	286.4	127.1	127.0 ± 2.5
76	482.5	261.2	169.5	169.5 ± 2.4	259.0	309.1	140.9	141.5 ± 2.7
80	567.5	288.8	191.4	191.5 ± 4.4	303.5	340.6	160.5	161.0 ± 3.5
83	637.5	310.3	208.7	209.8 ± 1.0	340.0	365.2	176.1	176.6 ± 1.8

In order to obtain the n -scaling law, we use function, $\tau = a \times (n - \delta_L)^b$ with a and b the fitting parameters, to fit the measured and calculated lifetimes, see lines in Figure 4. The fitting parameters of $b_{exp} = 2.55 \pm 0.02$ and $b_{theor} = 2.50 \pm 0.02$ for $|nD_{5/2}\rangle$, and $b_{exp} = 2.30 \pm 0.01$ and $b_{theor} = 2.27 \pm 0.01$ for $|nS_{1/2}\rangle$ state, respectively. The measurements of b agree with the calculations, and the difference of scaling magnitude b is 3% for $|nD_{5/2}\rangle$

state and 1% for $|nS_{1/2}\rangle$ state. The measured lifetime for both S - and D -type Rydberg state increases with the principal quantum number n .

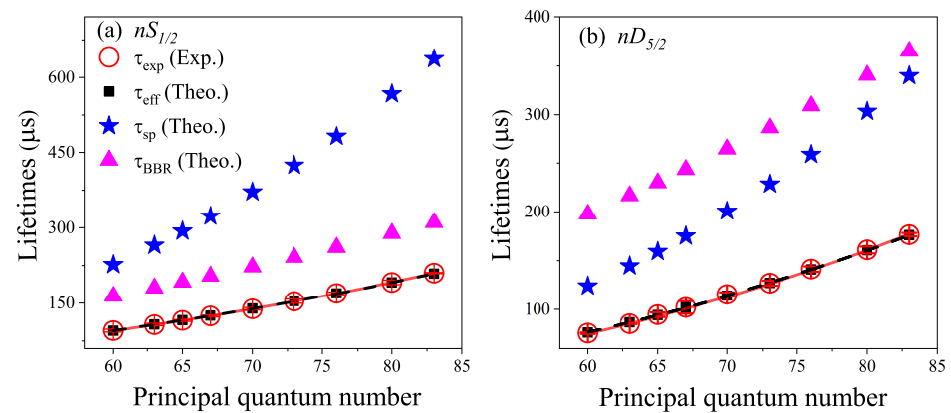


Figure 4. (Color online) (a) The measurements (red circles) and calculations (black squares) of $|nS_{1/2}\rangle$ atomic lifetimes as a function of the principal quantum number n . Error bars of data display the standard error of five independent measurements. The calculations of Equation (4) reproduce the experiments well. For comparison, we also present calculations of spontaneous radiation lifetime τ_{sp} (blue stars) and BBR lifetime τ_{BBR} (pink triangles). The red solid (black dashed) line indicates the fitting of the measured (calculated) lifetime with the function $\tau = a \times (n - \delta_L)^b$, with b displaying the scaling law. $b_{exp} = 2.30 \pm 0.01$ and $b_{theor} = 2.27 \pm 0.01$. (b) The same measurements and calculations as in (a) for $|nD_{5/2}\rangle$ state. $b_{exp} = 2.55 \pm 0.02$ and $b_{theor} = 2.50 \pm 0.02$.

In the Table 3, we present the comparison of our measurements and previous b value in literatures for different n range. In the first line of the table, the scaling magnitude b_{sp} for spontaneous radiation lifetime at $T = 0$ K is also listed. As expected, the lifetime scales as $\sim n^3$ both for $|nS_{1/2}\rangle$ and $|nD_{5/2}\rangle$ states. However, the scaling magnitude b_{exp} and b_{eff} in this work and in Ref. [15] are less than 3. The deviation of b from 3 may be attributed to the fact that the room temperature BBR enhances the decay rate of the Rydberg state, which may diminish the increase rate of lifetime comparing to the spontaneous radiation lifetime and lead to a reduction of the scaling magnitude of b .

Table 3. Comparison of measurements and calculations of n -scaling magnitude b of cesium Rydberg lifetime.

Lifetime	State	n -Range	b
τ_{sp} [5]	$nD_{5/2}$	$10 \leq n \leq 80$	3.00
	$nS_{1/2}$		2.99
τ_{eff} [5]	$nD_{5/2}$	$10 \leq n \leq 80$	2.56
	$nS_{1/2}$		2.39
τ_{exp} [15]	$nD_{5/2}$	$50 \leq n \leq 75$	2.45
τ_{eff} (this work)	$nD_{5/2}$	$60 \leq n \leq 83$	2.50 ± 0.02
	$nS_{1/2}$		2.27 ± 0.01
τ_{exp} (this work)	$nD_{5/2}$	$60 \leq n \leq 83$	2.55 ± 0.02
	$nS_{1/2}$		2.30 ± 0.01

4. Conclusions

We have measured the lifetime of cesium Rydberg atoms in the high state ($60 \leq n \leq 83$) and found that the blackbody radiation and Rydberg interaction would strongly enhance

the decay rate and shorten the lifetime of the given Rydberg state. For lower Rydberg atomic density, the measured lifetime shows a good agreement with the calculated effective lifetime τ_{eff} . The cross section can be extracted by fitting the measurement of decay rate as a function of the Rydberg atomic density, which is closer to the Rydberg geometric collision section. The calculated spontaneous lifetime displays n^3 scaling law [1,5]. However, the scaling b of lifetime measurement is $b_{exp} = 2.55$ (2.30) for $|nD_{5/2}\rangle$ ($|nS_{1/2}\rangle$) that is less than that of the spontaneous lifetime. The reduction of the scaling magnitude of b can be attributed to the BBR induced decay that enhances the decay rate of the Rydberg state. The results here demonstrate that the lifetimes are affected by the room temperature BBR radiation and the interaction between Rydberg atoms. In this work, we have measured the lifetime of $|nS_{1/2}\rangle$ and $|nD_{5/2}\rangle$ for $n = 60\text{--}83$. The agreement between the measurement and calculation of Rydberg lifetime displays that the calculation of effective lifetime accounting BBR in Ref. [5] can be extend to $n = 83$. It is noted that the superradiation effect has a negligible effect on the lifetime measurement in this work. When the Rydberg density is larger than $\sim 10^{10} \text{ cm}^{-3}$, the superradiation will strongly accelerate the decay rate and modify the lifetime of Rydberg state [4,25]. The high precision measurement of the lifetime provides a powerful tool for investigating the cross section for the quenching collision and also has a significant correction to quantum defects.

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