Theoretical hyperfine splittings of ^{7,9}Be^{2+} ions for future studies of nuclear properties

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The hyperfine structures of the $2\,^3S_1$ and $2\,^3P_J$ states of ^{7}Be^{2+} and ^{9}Be^{2+} are investigated within the framework of the nonrelativistic quantum electrodynamics (NRQED) [1], including relativistic and radiative corrections up to order $m\alpha^6$. Our results [2] are shown in Tables 1 and 2. The uncertainties of the calculated hyperfine splittings are on the order of tens of ppm, and for ^{9}Be^{2+} our results improve the previous theoretical and experimental values by at least two orders of magnitude. The improved sensitivity of the hyperfine splittings of ^{7,9}Be^{2+} to the nuclear Zemach radius and electric quadrupole moment opens the way to future measurements to extract the atomic physics values of these two nuclear properties to an accuracy of 5% or better.

Table 1: Theoretical hyperfine intervals in the $2\,^3S_1$ state of ^{7}Be^{2+} and ^{9}Be^{2+} with the Zemach radius $R_{\rm em} = 3.45(11)$ fm and $R_{\rm em} = 4.07(5)$ fm, respectively. The last column is the predicted accuracy of $R_{\rm em}$.

	$(J,F)-(J',F')$	ν (This work) cm^{-1}	Scholl *et al.* [3] cm^{-1}	$\lvert\delta R_{\rm em}/R_{\rm em}\rvert$ %
^{7}Be^{2+}	$(1,1/2)-(1,3/2)$	0.40952(1) at 24 ppm		5
	$(1,3/2)-(1,5/2)$	0.68250(1) at 15 ppm		3
^{9}Be^{2+}	$(1,1/2)-(1,3/2)$	0.344574(9) at 26 ppm	0.3448(10)	4
	$(1,3/2)-(1,5/2)$	0.574275(6) at 10 ppm	0.5740(11)	2

Table 2: Theoretical hyperfine intervals in the $2\,^3P_J$ state of ^{7}Be^{2+} and ^{9}Be^{2+} with the nuclear quadrupole moments $Q_d = -6.11$ fm^2 and $Q_d = 5.350(14)$ fm^2, respectively. The last column is the predicted accuracy of Q_d.

	$(J,F)-(J',F')$	$\nu(Q_d)$ (This work) cm^{-1}	Johnson *et al.* [4] cm^{-1}	Scholl *et al.* [3] cm^{-1}	$\lvert\delta Q_d/Q_d\rvert$ %
^{7}Be^{2+}	$(2,1/2)-(2,3/2)$	0.18726(1) at 53 ppm			4
	$(2,3/2)-(2,5/2)$	0.31574(1) at 32 ppm			5
	$(2,5/2)-(2,7/2)$	0.44953(1) at 22 ppm			4
	$(1,1/2)-(1,3/2)$	0.21130(1) at 47 ppm			3
	$(1,3/2)-(1,5/2)$	0.31346(1) at 32 ppm			5
^{9}Be^{2+}	$(2,1/2)-(2,3/2)$	0.158371(7) at 44 ppm	0.1581	0.1585(10)	3
	$(2,3/2)-(2,5/2)$	0.266123(4) at 15 ppm	0.2659	0.2659(11)	3
	$(2,5/2)-(2,7/2)$	0.377128(4) at 11 ppm	0.3773	0.3768(14)	2
	$(1,1/2)-(1,3/2)$	0.175126(4) at 23 ppm	0.1754	0.1751(10)	1
	$(1,3/2)-(1,5/2)$	0.265662(3) at 11 ppm	0.2654	0.2654(10)	2

[1] K. Pachucki *et al.*, Phys. Rev. A 85, 042517 (2012).
[2] X.-Q. Qi *et al.*, Phys. Rev. A 107, L010802 (2023).
[3] T. J. Scholl *et al.*, Phys. Rev. Lett. 71, 2188 (1993).
[4] W. R. Johnson *et al.*, Phys. Rev. A 55, 2728 (1997).