High-accuracy ab-initio calculations of magic wavelengths for the $2\,^3S_1 \rightarrow 2\,^1S_0$ transition of helium

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High-precision spectroscopy in helium has been achieved with sufficient accuracy to determine the fine-structure constant, to test QED theory, and to extract the nuclear charge radius. However, the determination of nuclear charge radius differences between ^{3}He and ^{4}He still disagree by 4σ from different frequency measurement of the $2\,^1S \rightarrow 2\,^3S$ and $2\,^3S \rightarrow 2\,^3P$ transitions [1, 2]. In order to measure the $2\,^1S \rightarrow 2\,^3S$ transition with sub-kHz precision, W. Vassen group in VU University designs a 319 nm magic wavelength trap to eliminate the ac Stark shift [3]. So far, there is lack of ab-initio calculation for the magic wavelengths of helium. In present work, a large-scale full-configuration-interaction calculation based on Dirac-Coulomb-Breit (DCB) Hamiltonian is performed for helium. Different from our previous RCI method [4], the mass shift operators are included directly into the DCB Hamiltonian. Furthermore, the non-relativistic calculations of helium are also carried out by using the Hylleraas-B-spline method. All the magic wavelengths from two different theoretical methods are consistent, and present RCI method predicted the magic wavelength 319.816 07(2) nm for ^{4}He, which provides theoretical support for experimental design of the magic wavelength optical trap.

No.	Hyllerass-B-splines	RCI	Ref. [3]
1	412.16(4)	412.167(1)	411.863
2	352.299(6)	352.336 7(1)	352.242
3	338.641 3(2)	338.683 5(1)	338.644
4	331.240 3(1)	331.284 63(2)	331.268
5	326.633 8(1)	326.678 87(2)	326.672
6	323.544 5(1)	323.589 79(2)	323.587
7	321.366 2(1)	321.411 36(2)	321.409
8	319.771 1(1)	319.816 07(2)	319.815
9	318.566 8(1)	318.611 62(5)	318.611

Table 1: The magic wavelengths (in nm) for the $2\,^1S_0 \rightarrow 2\,^3S_1(M_J = \pm 1)$ transition of ^{4}He.

[1] R. van Rooij, J. S. Borbely, J. Simonet, M. D. Hoogerland, K. S. E. Eikema, R. A. Rozendaal, and W. Vassen, Science 333, 196 (2011).

[2] P. Cancio Pastor, L. Consolino, G. Giusfredi, P. De Natale, M. Inguscio, V. A. Yerokhin, and K. Pachucki, Phys. Rev. Lett. 108, 143001 (2012).

[3] R. P. M. J. W. Notermans, R. J. Rengelink, K. A. H. van Leeuwen, and W. Vassen, Phys. Rev. A 90, 052508 (2014).

[4] Y. H. Zhang, L. Y. Tang, X. Z. Zhang, and T. Y. Shi, Phys. Rev. A 93, 052516 (2016).