Optical clocks based on highly charged ions with enhanced sensitivity to variations in the fundamental constants

Julian Berengut, Andrew Ong, Vladimir Dzuba, Victor Flambaum

School of Physics, University of New South Wales, Sydney NSW, Australia

Email: jcb@phys.unsw.edu.au

Optical transitions can occur in some highly charged ions (HCIs) when the ion stage and nuclear charge are tuned such that orbitals with different principal quantum number and angular momentum are nearly degenerate[1]. In these cases the transition energy may be within laser range even though the ionisation energy is large (of order several hundred eV). We have identified several such systems and shown that they have a number of properties that could make them suitable for atomic clocks with high accuracy. Strong E1 transitions provide options for laser cooling and trapping, while narrow transitions can be used for high-precision spectroscopy and tests of fundamental physics. In particular we found transitions that would have the highest sensitivity to variation of the fine-structure constant ever seen in atomic systems[2,3].

HCI clocks utilising these transitions could confirm the indications of a spatial gradient in the fine-structure constant observed in quasar absorption spectra data[4]. These results, from a very large study of around 300 quasar absorption systems using data from both the Keck telescope and the Very Large Telescope, provide hints that there is a spatial gradient in the variation of the fine structure constant, α. In one direction on the sky α appears to have been smaller in the past, while in the other direction it appears to have been larger. The data from both telescopes give the same direction and magnitude for the α-gradient.

If this gradient is correct, then the motion of the Earth through it implies an annual variation at the level of 10^{-19} per year[5], two orders of magnitude below current best limits[6]. The highly-charged ion clocks proposed could probe this limit if experimental accuracy can reach that of the Al^+/Hg^+ clocks.

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