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Development of an Ytterbium-ion optical clock to explore fundamental science

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At the Precision & Quantum Measurement lab (PQM-lab) at IUCAA, we are focused on developing quantum phenomena-based technologies for accurate sensing and performing precision measurements to explore the fundamental aspects of science. We are developing an ultrahigh accurate and highly stabilized optical reference derived from an optical atomic clock. The heart of the experimental setup is a trapped ytterbium-ion-based quantum clock. For this, we shall probe the highly forbidden electric octupole (E3) transition at 467 nm wavelength of a single trapped and laser-cooled ytterbium-ion. This particular clock transition is chosen due to its high sensitivity to possible fine-structure constant variation and Lorentz symmetry violation. To excite that clock transition, an ultra-stable sub-Hz line-width laser will be produced by referencing an indigenously developed ultra-stable Fabry-Pérot cavity, which we have already designed and fabricated [1], and installation is in progress. Upon building the optical clock, the change in the tick rates of such clocks alters by unimaginably tiny perturbations of the energy states associated with the clock transitions. The resulting shift in tick rates of the clock allows for the probe of any variations of the fine-structure constant, breaking of Lorentz symmetry, time dilation, geodetic measurement, and so on. For such scientific explorations, the lab-based clocks must be part of a geographically distributed “optical clock network,” which is expected to shape up in India in the coming years as few groups have started developing optical clocks in the recent past [2]. The ultra-stable, nearly monochromatic photons generated using the reference clocks must be disseminated from one node to another within the clock network using “phase stabilized optical fibers” to establish such a network. We have already developed the hardware required for that technology and tested its performance using a 3.3 km geographically distributed network also in fiber spools of up to 77 km lengths [3]. In the meeting, I shall describe the present status of our ongoing work towards building the ytterbium-ion optical clock.

1. “Modelling and design of ultra-high stable Fabry-Pérot cavity”, Sankalpa Banerjee, Stanley Johnson, Yutiben Vaghasia, Kanik Palodhi, Sandip Haldar, and S. De, Int. J. of Mech. Sciences **250**, 108299 (2023).

2. “Indigenisation of the Quantum Clock: An Indispensable Tool for Modern Technologies”, S. De, A. Sharma, Atoms **11**, 71 (2023).

3. “Coherent optical fiber for In-phase photon transfer”, Stanley Johnson, Sujaya Das Gupta, Sankalpa Banerjee, Aman Gangwar, Subhadep De, Indian Patent App No – 202321045035 (2024).