Questionnaire
previous to the 2007 meeting of the
CCL-CCTF Frequency Standards Working Group

Note: Results will be considered only if there is a publication or at least acceptance for publication at the date of the meeting.

1. Have you made absolute frequency measurements of radiations included in the CCL list of recommended radiations (Mise en Pratique 2005)?

   Yes [ ] No [x]

   If yes, please list the values and uncertainties obtained and the methods used and refer to the publication(s) in which they may be found. Please be sure to include measurements made in other laboratories in your country.

   1.1. If yes, indicate for each one whether you think that any of these measurements should modify the current value and uncertainty already on the list.

   Yes [ ] No [ ]

   (add as many lines as necessary)

2. Have you made absolute frequency measurements of radiations included in the CCTF list of secondary representations of the second?

   Yes [x] No [ ]

   2.1. If yes, please list the values and uncertainties obtained and the methods used and refer to the publication in which they may be found. Please be sure to include measurements made in other laboratories in your country.

1S0-3P0 transition of Sr in an optical lattice clock: 429 228 004 229 873.6 (1.1) Hz. R. Le Targat, PhD dissertation: http://tel.archives-ouvertes.fr/tel-00170038/fr/

   2.2. If yes, indicate for each one whether you think that any of these measurements should be proposed as an update of existing value and uncertainty to be considered at the next CCL-CCTF Joint WG meeting just prior to the CCTF (2008/2009).

   Yes [x] No [ ]

   (add as many lines as necessary)

3. Have you made absolute frequency measurements of other radiations <u>not</u> included in these lists?

   Yes [ ] No [x]

If yes, please list the values and uncertainties obtained and the methods used and refer to the publication in which they may be found. Please be sure to include measurements made in other laboratories in your country.

3.1. If yes, indicate if any of these sources should be included in a updated list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second, and present your arguments for a positive assessment.

Recommended for the MeP:

Yes ☐ No ☐

Recommended for secondary representation of the second

Yes ☐ No ☐

(add as many lines as necessary)

4. Are you currently developing new frequency sources or are you aware of such sources developed in your country?

Yes ☒ No ☐

If yes, please give a brief description of your experiment.

Neutral mercury: an interesting candidate for an optical lattice clock

One interesting candidate for an optical lattice clock is neutral mercury (Hg). Hg has an alkaline-earth like electronic structure with a $^1S_0$-$^3P_0$ intercombination transition which is totally forbidden for bosonic natural isotopes and weakly allowed by hyperfine mixing for fermions. The wavelength of this transition is 265.6 nm. The natural linewidth of the transition has been calculated and measured to be in the 100 mHz range for fermions [1]. As for other proposed neutral atoms (Ca, Sr, Yb), bosonic isotopes can also be used for an optical clock provided a quenching scheme is used [2]. One possible foreseeable limitation of the accuracy of optical lattice clock, when accuracy below 10^{-17} is targeted, is the blackbody radiation shift. In this respect, Hg is an interesting candidate with an estimated blackbody radiation shift of 2×10^{-16}, between 10 and 100 times smaller than other alkaline-earth atoms [3,4]. Hg also possesses 6 abundant isotopes (2 fermions and 4 bosons, natural abundance >6%) and 1 relatively rare, although probably usable, bosonic isotope (^{196}Hg) with a 0.15% natural abundance. All isotopes have no more than F=3/2 (^{201}Hg) total spin in the ground state.

Two other important considerations to make Hg a reasonable candidate is the feasibility of laser cooling and of an non-perturbing lattice trap. Unlike other alkaline-earth candidate, the strongly allowed $^1S_0$-$^1P_1$ transition is not practical (185 nm) and has a very high Doppler cooling temperature. On the other hand, the $^1S_0$-$^3P_1$ transition at 254 nm with a natural linewidth of 1.2 MHz should lead to efficient magneto-optical trapping together with a low Doppler cooling temperature of 30 µK. Unlike the 185 nm radiation, the 254 nm wavelength can be accessed with sufficient power using available technologies. Similarly, it has been shown, that Hg possesses at least one useable “magic wavelength” for the non-perturbing dipole trap [5,6,8] at 360 nm.

To conclude, Hg is an interesting candidate for an optical lattice clock. One interesting metrological feature is the smallness of the blackbody radiation shift. Also, Hg has a high sensitivity to α variation [7]. One of the challenging aspects of using Hg for an optical clock is the necessity to generate and use UV laser light with relatively high power.

Development of an optical lattice clock based on mercury at SYRTE

Based on the above considerations, SYRTE has started developing an optical lattice clock based on Hg. This project has started in 2005 with the financial support coming most notably form LNE, the French NMI. The laser source for laser cooling is based on a commercial frequency doubled disk laser at 1014.9 nm delivering >3 W at 507 nm. More than 700mW have been observed at 254 nm after resonant frequency doubling with BBO crystal. Saturated absorption spectroscopy of a Hg vapor has been performed in order to stabilized this laser source. The laser system has been stabilized to the atomic line. Optimization is being done to minimize the residual frequency noise. This is required for achieving lowest possible temperature with 1.2 MHz wide cooling transition. After this step is completed, the 254 nm will be ready for laser cooling. The construction of the vacuum chamber is completed. The light for probing the clock transition at 265.6 nm is obtained by quadrupling an alpha-DFB diode laser. Resonant frequency doubling of the alpha-DFB diode laser at 1062.4 nm using a PPKTP crystal leads to 140 mW at 531.2 nm. A second resonant frequency doubling with a BBO crystal leads to >4 mW at 265.6 nm which should be sufficient for all envisioned experiments. The alpha-DFB diode laser will be stabilized to an ultra stable infrared source (both injection locking and phase locking have been tested successfully) based on a fiber laser at 1062.4 nm locked to an ultra stable cavity. This ultra stable light source is now close to completion. With reasonable optimism, we are targeting to observe laser cooling in 2007 and to probe the clock transition for the first time by the beginning of 2008. We are also expecting to operate and to characterize the ultra stable light source in 2007. 2007/2008 will also be devoted to the development of the optical lattice trap (laser sources, build-up cavity, and modified vacuum chamber) and of various repump lasers.

[1] M.C. Bigeon, Journal de Physique **28**, 51 (1967)
Probabilité de transition de la raie 6 1S0 --- 6 3P0 du mercure

[2] A. V. Taichenachev, V. I. Yudin, C. W. Oates, C. W. Hoyt, Z. W. Barber, and L. Hollberg, Phys. Rev. Lett. **96**, 083001 (2006)
Magnetic Field-Induced Spectroscopy of Forbidden Optical Transitions with Application to Lattice-Based Optical Atomic Clocks

[3] V. Pal’chikov, private communications (2004)

[4] Sergey G. Porsev, Andrei Derevianko, ArXiv:physics/0602082 (2006)
Multipolar theory of black-body radiation shift of atomic energy levels and its implications for optical lattice clocks

[5] V. Pal’chikov, private communications (2004)

[6] V. D. Ovsiannikov and V. G. Pal'chikov and H. Katori and M. Takamoto, Quantum Electronics **36**, 3 (2006)
Polarisation and dispersion of light shifts in highly stable optical frequency standards

[7] E. J. Angstmann, V. A. Dzuba, and V. V. Flambaum, Phys. Rev. A **70**, 014102 (2004)

Relativistic effects in two valence-electron atoms and ions and the search for variation of the fine-structure constant

[8] V. Pal'chikov et al., EFTF-FCS, Geneva (2007)

PIIM (Marseille university) is developing an optical clock with a trapped Ca+ ion.

NAME: Pierre Lemonde……………………………………………………………………

INSTITUTE: LNE-SYRTE…………………………………………………………………

Note: After the decision of the CIPM in autumn 2006

that

- the CCL-*Mise en Pratique* WG and CCL/CCTF JWG be combined into a single CCL-CCTF frequency standards working group,
- the *Mise en Pratique*-CCL list of Recommended Radiations and CCTF Secondary Representation list be combined into a single new list of "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second",
- other frequencies may be proposed, evaluated and maintained on the frequency standards list by the CCL-CCTF frequency standards WG, not all of which are adopted as CCL-preferred radiations or CCTF-accepted representations,
- the CCTF consider and recommends those frequencies which it proposes the CIPM to accept as secondary representations of the second,
- the CCL considers and recommends those frequencies which it deems important for use in high accuracy length metrology, and
- the frequency values list is maintained on the BIPM website.

the CCL-CCTF frequency standards working group at its meeting in September 2007 will thus be required

1. to recommend to the CCL, frequency standards to be added to the list of recommended radiations,
2. to follow the development of frequency standards to be considered at the next CCTF as possible secondary representations of the second (no decision before the next CCTF),
3. to recommend other frequencies relevant for science or technology.

Additional information:

The current list of recommended frequencies as secondary representations of the second contains

- the unperturbed ground-state hyperfine quantum transition of ^{87}Rb with a
  frequency of f (^{87}Rb) = 6 834 682 610.904 324 Hz
  and an estimated relative standard uncertainty of 3×10^{-15},

- the unperturbed optical $5d^{10}\ 6s\ ^2S_{1/2}$ (F = 0) – $5d^9\ 6s^2\ ^2D_{5/2}$ (F =2)
  transition of the ^{199}Hg+ ion with a frequency of
  f (^{199}Hg+) = 1 064 721 609 899 145 Hz
  and a relative standard uncertainty of 3×10^{-15},

- the unperturbed optical $5s\ ^2S_{1/2}$ – $4d\ ^2D_{5/2}$ transition of the $^{88}Sr^+$ ion with a
  frequency of f ($^{88}Sr^+$) = 444 779 044 095 484 Hz
  and a relative uncertainty of 7×10^{-15},

- the unperturbed optical $6s\ ^2S_{1/2}$ (F = 0) – $5d\ ^2D_{3/2}$ (F =2) transition of the
  $^{171}Yb^+$ ion
  with a frequency of f ($^{171}Yb^+$) = 688 358 979 309 308 Hz
  and a relative standard uncertainty of 9×10^{-15},

- the unperturbed optical transition $5s^2\ ^1S_0$ – $5s5p\ ^3P_0$ ^{87}Sr neutral atom with a
  frequency of f (^{87}Sr) = 429 228 004 229 877 Hz
  and a relative standard uncertainty of 1.5×10^{-14}.