Problem Set 1 #3

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1 Problem Description

The best oscillators are based on atomic transitions. Cesium transitions are the basis of modern-day atomic clocks. Their is increasing interest in using transitions of an ytterbium lattice, and future clocks are likely to based on these transitions. What are the operating frequencies and linewidths of these oscillators? What are the corresponding quality factors?

2 Solution

2.1 Cesium Oscillators

Cesium oscillators operate on the same atomic principles as rubidium oscillators. As opposed to rubidium, which has 4 complete shells and 1 valence electron on the 5 level, cesium has 5 complete shells and 1 valence electron on the 6th level. Despite the different number of complete electron shells, the lone valence electron means that cesium operates under the hyperfine splitting principle in the same way that rubidium does[1]. As a result, cesium clocks use the hyperfine frequency of cesium between the first two energy levels, which is a frequency of about 9.2 GHz. Because cesium oscillators rely of these transitions, they maintain the high Q factor and stability of rubidium, usually with a Q factor of around a few parts per magnitude of 10^8 and a FWHM of 10-90 Hz.

2.2 Ytterbium Lattices

Ytterbium lattices represent the next possibly generation of atomic clock through the elimination of several key issues that appear with laser spectroscopy. Two large issues are Doppler Spreading and recoil. Doppler Spreading is a result of electron orbitals favoring different frequencies, resulting in blue and red shifting of lasers that can overshadow hyperfine transitions. Recoil of atoms can also create frequency shifts through the creation of a pseudo "lens" that can distort the frequencies that the atoms are traveling at. It has been recognized recently that a lattice of atoms bound together in a tight structure can eliminate both

[1]For a more detailed explanation of hyperfine splitting, reference the Problem 2 solution

of these problems, but a specific element needs to be chosen that has both a narrow linewidth and relative resistance to lattice perturbations. Ytterbium has been identified as a good fit for these requirements and research is ongoing to create ytterbium lattice clocks because of this. Ytterbium lattice clocks have a hyperfine frequency of about 518.3 THz, magnitudes faster than cesium or rubidium. The linewidth and stability are far improved as well, with a Q factor of around $10^{1}7$ and a FWHM of about 10 mHz.

3 Works Cited

[1] "Time and Frequency from A to Z, Q to Ra," National Institute of Standards and Technology, 2016. https://www.nist.gov/time-and-frequency-services/q-ra

[2] "Hyperfine Interaction," Eidgenössiche Technische Hochschule Zürich, 2019. https://epr.ethz.ch/education/basic-concepts-of-epr/int–with-nucl–spins/hyperfine-interaction.html

[3] C. W. Hoyt, Z. W. Barber, et al., "Observation and absolute frequency measurements of the S_0^1-P_0^3 optical clock transition in ytterbium," National Institute of Standards and Technology, 2018. https://arxiv.org/pdf/physics/0503240.pdf

3.1 Works Cited Uses

Section 2.1 - Completed using [1] and [2]
Section 2.2 - Completed using [3]