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Comment on "The Millman Effect in Cesium Beam Atomic Frequency Standards"

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Abstract

In a recent paper entitled "The Millman Effect in Cesium Beam Atomic Frequency Standards" (Mungall, A.G.: Metrologia *12*, 151 (1976)) a systematic frequency shift was observed and explained in terms of the Millman effect. The purpose of this note is to suggest that an alternative explanation be sought for the observed results.

In a recent paper entitled "The Millman Effect in Cesium Beam Atomic Frequency Standards [1], a systematic frequency shift was observed and explained in terms of the Millman effect [2]. The purpose of this note is to suggest that an alternative explanation be sought for the observed results.

The essential features of the Millman effect were first explained as a result of Millman's measurements on nuclear moments in a molecular beam apparatus [2]. For these measurements, a nuclear spin magnetic moment is allowed to precess in an externally applied (calibrated) static magnetic field. An oscillating (standing wave) magnetic field is also applied and if the frequency is properly adjusted the spin undergoes a transition (spin "flip") and thus changes magnetic quantum state. The oscillating field can be thought of as comprised of the sum of two oppositely rotating magnetic fields; if high enough resolution is obtained,* only one of these rotating components is responsible for the transition. The relevant frequency is then the angular frequency of this component relative to the laboratory static magnetic field.

The Millman effect comes about if the component of the oscillating magnetic field which is perpendicular to the static field changes direction along the length of the molecular (atomic) beam. For this case, the oscillating field can again be resolved into two oppositely rotating components; however, the angular frequency of the relevant component is either increased or diminished by an amount

$$\delta\omega_m = \frac{\gamma v}{l} \tag{1}$$

The sign of this term depends on the sign of the magnetic moment, static field direction and beam geometry. γ is the angle through which the oscillating magnetic field rotates (in the plane perpendicular to the static field), v is atomic velocity and l is the length of the interaction region. For a more detailed description see [2] and [3]. Such a shift occurs for $|\Delta M| = 1$ transitions in general, for example in the spin flip transitions discussed by Millman and in $\Delta M = \pm 1$ hyperfine transitions.

Recently Hahn [4] theorized that the Millman effect would also apply to $\Delta M = 0$ hyperfine transitions, for instance the clock transition of the cesium beam frequency standards. More recently Mungall [1] observed a frequency shift in the NRC cesium beam standard, CsV, which changes sign upon beam reversal or static magnetic field reversal. He attributes this shift to the Millman effect.

The purpose of this note is not to comment on the validity of the measurement of [1] but rather to point out that this measured shift is not related to the usual Millman effect. (This has been recognized already in discussions and internal reports [5].) Specifically, for $\Delta M = 0$ hyperfine transitions including the cesium clock transition, no frequency shift should occur if the relative orientation of static and oscillating magnetic field changes spatially inside the transition region of an atomic (molecular) beam apparatus.

To see this we first assume that the spatial orientation of the static field changes gradually in space so that as the atom moves through this field it adiabatically follows this field [3]. If this is not the case, Majorana transitions [3] may occur and in certain extreme cases may cause frequency pulling [6] but this is not the Millman effect. With this assumption we consider a coordinate system whose z axis is always fixed along the static field direction. In this coordinate system the oscillating magnetic field can

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* For low Q resonances due to high applied rf power the Block-Siegert shift is important. See Block, F., Siegert, A.: Phys. Rev. 57, 522 (1940).

be resolved into a component along the z axis and a component in the x–y plane. Only the z component of the rf field is important; the rf field component in the x–y plane cannot contribute to $\Delta M = 0$ transitions [3]. Therefore if the relative orientation of static and rf field changes, the amplitude of the z component may change but this amplitude modulation should not cause a frequency pulling [7].

It is important to state that the phase of the z component of the rf field is always the same as the phase of the total rf field. It does not depend on the angle between them as Hahn seems to assume [4]. From the above considerations, there appears to be no basis for the type of frequency shift assumed, in particular, there should be no Millman effect for $\Delta M = 0$ hyperfine transitions.

Other conditions could lead to the type of effect reported in [1]; however it is difficult to speculate on the exact cause of such an effect without more complete knowledge of experimental details. Nevertheless, it does seem implausible to us that the measured shift arises from the effect discussed by Millman.

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