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Universal Upper Bound for the Tunneling Rate of a Large Quantum Spin

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Abstract. An upper bound is derived for the tunneling rate of a spin with large spin quantum number S. The bound is *universal* in the sense that it does not depend on the specific form of the anisotropy (i.e., the potential barrier). The method of proof relies on the exponential localization theorem of Fröhlich and Lieb and lends precise support to a rather suggestive interpretation put forth in a WKB analysis of van Hemmen and Sütő. The resulting bound agrees with their expression for the tunneling rate in the limit of large S.

1. Introduction

Macroscopic quantum tunneling, i.e., the penetration of a classically forbidden barrier by a macroscopic system, has aroused a considerable amount of interest [1]. The motion of the system, a collection of particles, is usually described by a single coordinate which is allowed to tunnel through a barrier between two minima of an effective potential. However, not only a system of particles but also a large quantum spin can tunnel [2–6]. For example, at low temperatures the long-time behavior of the thermoremanent magnetization (TRM) of a spin glass with uniaxial or unidirectional anisotropy is dominated [7] by the tunneling of large, mainly ferromagnetic clusters. The same type of dynamics also occurs in magnetically anisotropic media [8] where the magnetization of a single domain can tunnel through an energy barrier between easy directions. Since at low temperatures the clusters are frozen (i.e., the magnetic moments stick together), it is reasonable to describe them [7, 8], at least in first approximation, by a *single* spin with a *large* spin quantum number S.

We consider a single quantum spin of fixed total angular momentum S and denote by $\hat{S}_x$, $\hat{S}_y$, and $\hat{S}_z$ the usual angular momentum operators with

$$[\hat{S}_x, \hat{S}_y] = i\hbar \hat{S}_z, \quad \text{and cyclically; } \hat{S}_\pm = \hat{S}_x \pm i\hat{S}_y. \tag{1.1}$$

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