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Nucleon 3D intrinsic spin structure from the weak-neutral axial-vector form factors

We present the first systematic study of the relativistic intrinsic spin structure of a general spin-1/2 hadron in position space. We show in particular that the slope of the nucleon axial form factor $G_A^Z(Q^2)$ in the forward limit, conventionally denoted as $R_A^2 \equiv -\frac{6}{G_A^Z(0)} \frac{\mathrm{d}G_A^Z(Q^2)}{\mathrm{d}Q^2}\Big|_{Q^2=0}$ in the literature, does not faithfully characterize the size of the weak axial charge content of the nucleon in the Breit frame, but corresponds instead to a contribution to the nucleon 3D spin radius $r_{\text{spin}} \equiv \sqrt{\langle r_{\text{spin}}^2 \rangle}$, with $\langle r_{\text{spin}}^2 \rangle = R_A^2 + \frac{1}{4M^2}\left(1 + \frac{G_P^Z(0)}{G_A^Z(0)}\right)$. We derive explicit expressions for the spin radius in different frames, and find in general additional contributions that depend on both the nucleon mass and the forward values of the axial-vector form factors $G_A^Z(0)$ and $G_P^Z(0)$. We also show that the second-class current contribution associated with the induced pseudo-tensor form factor $G_T^Z(Q^2)$ does not contribute in fact to both the nucleon axial and spin radii. Our work paves a new and direct way for investigating the nucleon 3D intrinsic spin structures using the weak-neutral axial-vector form factors $G_{A,P,T}^Z(Q^2)$ extracted from elastic (anti)neutrino-nucleon scattering data, or calculated in lattice QCD and various models and approaches.

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