

Fermion spin state s is a unit vector in \mathbb{C}^2 .

$$|s\rangle = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix}, \quad c_1^* c_1 + c_2^* c_2 = 1$$

Here is $|s\rangle$ as a linear combination of basis states “up” and “down.”

$$|s\rangle = c_1|u\rangle + c_2|d\rangle, \quad |u\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |d\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

These are the spin operators.

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Expectation of spin operators is a projection of s onto Euclidean space.

$$\langle x \rangle = \langle s | \sigma_x | s \rangle, \quad \langle y \rangle = \langle s | \sigma_y | s \rangle, \quad \langle z \rangle = \langle s | \sigma_z | s \rangle$$

Let \mathbf{u} be the spin direction vector formed from s .

$$\mathbf{u} = \begin{pmatrix} \langle x \rangle \\ \langle y \rangle \\ \langle z \rangle \end{pmatrix} = \langle s | \boldsymbol{\sigma} | s \rangle, \quad \boldsymbol{\sigma} = \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix}$$

Let θ and ϕ be polar and azimuth angles such that

$$\mathbf{u} = \begin{pmatrix} \sin \theta \cos \phi \\ \sin \theta \sin \phi \\ \cos \theta \end{pmatrix}$$

Then

$$|s\rangle = \begin{pmatrix} \cos \frac{\theta}{2} \\ \sin \frac{\theta}{2} \exp(i\phi) \end{pmatrix} = \cos \frac{\theta}{2} |u\rangle + \sin \frac{\theta}{2} \exp(i\phi) |d\rangle$$

In component notation $\boldsymbol{\sigma} = \sigma^{\alpha\beta}{}_{\gamma}$ hence

$$u^\alpha = s_\beta^* \sigma^{\alpha\beta}{}_{\gamma} s^\gamma$$

A transpose swaps α and β so that summed-over indices are adjacent.

$$u^\alpha = s_\beta^* \sigma^{\beta\alpha}{}_{\gamma} s^\gamma$$

Hence the Eigenmath code is

$$\mathbf{u} = \text{dot}(\text{conj}(\mathbf{s}), \text{transpose}(\mathbf{sigma}), \mathbf{s})$$