

## Spin part 2

From the previous section we have for the  $z$  direction

$$\Pr(+) = |\langle z_+ | s \rangle|^2 = \frac{1}{2} + \frac{1}{2} \cos \theta$$

$$\Pr(-) = |\langle z_- | s \rangle|^2 = \frac{1}{2} - \frac{1}{2} \cos \theta$$

If  $|s\rangle$  is not an eigenstate then the result of measuring  $|s\rangle$  is a random value. For example, let  $\theta = \pi/3$ . Then  $\cos \theta = \frac{1}{2}$  and the probabilities are

$$\Pr(+) = \frac{3}{4}$$

$$\Pr(-) = \frac{1}{4}$$

Expected value is a useful statistic for analyzing random data. By experimental design, a measurement that results in “+” indicates a spin value of  $+\frac{\hbar}{2}$  and “-” indicates a spin value of  $-\frac{\hbar}{2}$ . Hence the expected value is

$$\left(+\frac{\hbar}{2}\right) \Pr(+) + \left(-\frac{\hbar}{2}\right) \Pr(-)$$

For state  $|s\rangle$  such that  $\theta = \pi/3$  the expected value in the  $z$  direction is

$$\left(+\frac{\hbar}{2}\right) \frac{3}{4} + \left(-\frac{\hbar}{2}\right) \frac{1}{4} = \frac{\hbar}{4}$$

Expected values can be computed directly from  $|s\rangle$  by introducing the following matrices.

$$S_x = \frac{\hbar}{2} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad S_y = \frac{\hbar}{2} \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \quad S_z = \frac{\hbar}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Then

$$\langle S_x \rangle = \langle s | S_x | s \rangle \quad \langle S_y \rangle = \langle s | S_y | s \rangle \quad \langle S_z \rangle = \langle s | S_z | s \rangle$$

Returning to the example  $\theta = \pi/3$  we have

$$|s\rangle = \begin{pmatrix} \frac{\sqrt{3}}{2} \\ \frac{1}{2}e^{i\phi} \end{pmatrix}$$

Hence the expected value in the  $z$  direction is

$$\langle S_z \rangle = \langle s | S_z | s \rangle = \begin{pmatrix} \frac{\sqrt{3}}{2} \\ \frac{1}{2}e^{i\phi} \end{pmatrix}^\dagger \frac{\hbar}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} \frac{\sqrt{3}}{2} \\ \frac{1}{2}e^{i\phi} \end{pmatrix} = \frac{\hbar}{4}$$

Eigenmath script