Separable and Entangled

Bavana Varun Satya Raj

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Theory

Consider the state $|\psi>= \frac{|00>+|11>+p(|01>+|10>)}{\sqrt{2+2p^2}}$,
Here, when p=0 we have the Bell State $|\psi>= \frac{|00>+|11>}{\sqrt{2}}$
and when p=1, we have $|\psi>= \frac{|00>+|11>+(|01>+|10>)}{2}$, which in turn is
$|\psi>= \frac{|0>+|1>)}{\sqrt{2}} \otimes \frac{|0>+|1>)}{\sqrt{2}}$, this is a separable state.

Hence as we increase p from 0 to 1, we go from a maximally entangled state to a separable state.

Code

Importing Required Modules

1. First we import the necessary packages:
2. Numpy enables us to do Tensor product, Matrix multiplication etc
3. scipy stats ortho group imports orthonormal vectors
4. matplotlib.pyplot enables us to plot graphs

Logic

runge=np.arange(0,1,0.01):
creates an array runge with values ranging from 0 to 1 with step size 0.01.(This Runge is our p)

sx=np.array([[0,1],[1,0]])
sy=np.array([[0,-1j],[1j,0]])
sz=np.array([[1,0],[0,-1]])
The above are my Pauli Spin Matrices σ_x,σ_y,σ_z, respetively

$x = orthogroup.rvs(3)$
$y = orthogroup.rvs(3)$
The above assigns to x and y orthonormal matrices

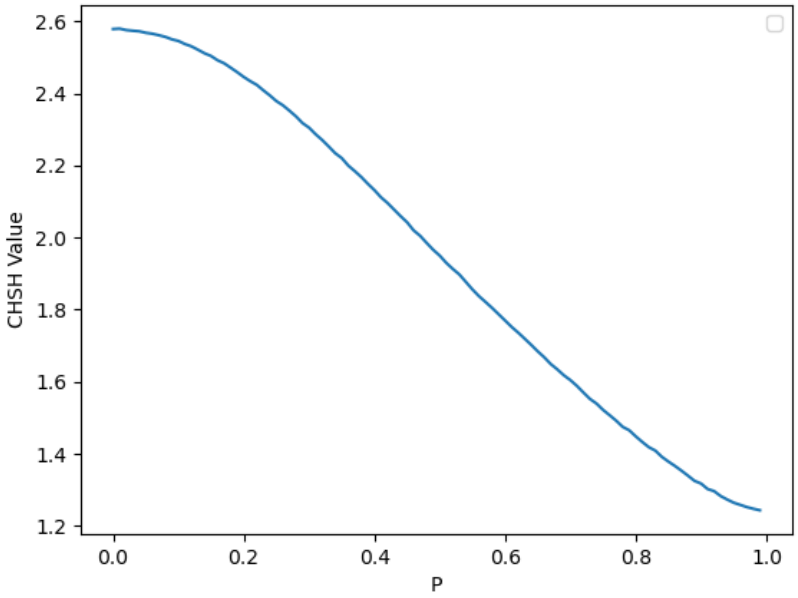
$$a1 = x[0], a2 = x[1], a3 = x[2], b1 = y[0], b2 = y[1], b3 = y[2], x^2$$

Assigning each row of x(y) to a1,a2,a3 to get three orthonormal vectors.

psi=np.array([1,p,p,1])
psi=psi/(np.linalg.norm(psi))
Assigning our state and normalizing it.

$def d(a, b)$:
$s1 = a[0] * sx + a[1] * sy + a[2] * sz$
$s2 = b[0] * sx + b[1] * sy + b[2] * sz$
$s = np.kron(s1, s2)$
$temp = np.matmul(psi, np.matmul(s, psi))$
return temp
Here 's1' and 's2' each represent $\sigma.\bar{a}$ and $\sigma.\bar{b}$ respectively 's' is the Tensor product of s1 and s2.
'temp' is the expectation value.

What we do later is, for each value of 'p' we find the maximum CHSH value for 100000 times(each time the orthonormal triads being different) and take mean of all those thousand maxima.
Hence, for each p we have the average of maxima taken 100000 times and plot the results



Numerical Result