For these problems, use the simulation "Entanglement: the nature of quantum correlations".

1) Have a play with the simulation for a few minutes, getting to understand the controls and displays. Note down five things about the controls and displayed quantities that you have found out.

2) (a) Explain in words the meaning of the probabilities P_{same} and P_{opp} and the correlation coefficient $E(AB)$ shown in the simulation. Step 2 of the Step-by-step Explanation explains the correlation coefficient. From the definition, what range of values are possible for the correlation coefficient?

Assume that both SGAs are oriented along Z. Consider the case where the particle pairs are described by the spin state $|\uparrow_A\rangle\,|\downarrow_B\rangle$ (state 1).

(b) What will Alice and Bob measure individually? What will they find when they compare their results for each pair?

(c) Determine the values of P_{same}, P_{opp} and $E(AB)$ for this situation.

3) Consider the entangled state (state 3) shown in the simulation. Again, both SGAs are oriented along Z.

(a) Compare the results of Alice and Bob for the entangled state (state 3) with their results for the state $|\uparrow_A\rangle\,|\downarrow_B\rangle$ (state 1). List the ways in which the results are similar and different.

(b) Compare the results of Alice and Bob for the entangled state (state 3) with their results for the state $\frac{1}{2}(|\uparrow_A\rangle\,|\uparrow_B\rangle - |\downarrow_A\rangle\,|\downarrow_B\rangle + |\uparrow_A\rangle\,|\downarrow_B\rangle - |\downarrow_A\rangle\,|\uparrow_B\rangle)$ (state 2) shown in the simulation. List the ways in which the results are similar and different.

For questions 4 to 6, consider both orientations of the SGAs (along Z and X).

4) A product state is a two-particle quantum state that can be written as a product of two individual quantum states, one for particle A and one for particle B.

(a) Does a product state imply that the spins of the particles have definite values? Explain using the states shown in the simulation. Choose the tick box to show quantum states as products.

(b) Entangled states are not product states. Interpret this statement physically.

5) In what ways are the anticorrelations found in the entangled state (state 3) stronger than those found in the product states (states 1 and 2)?

6) Imagine that there are two sources of particle pairs, one emitting particles in the state$|\uparrow_A>|\downarrow_B>$, the other in the state $|\downarrow_A>|\uparrow_B>$. The sources emit particle pairs so that on average, 50% of the particle pairs sent to Alice and Bob are in the state $|\uparrow_A>|\downarrow_B>$, the other 50% are sent in the state $|\downarrow_A>|\uparrow_B>$. This is called a random mixture of pairs.

Using the setup in the simulation, could Alice and Bob experimentally determine whether they are making measurements on such a random mixture as opposed to making measurements on the entangled state 3 shown? Explain your reasoning.

7) Show that the entangled state in the simulation (state 3) cannot be written as a product of two single-particle states. Start by assuming that you could write state 3 as a product state $\left(a|\uparrow_A> + b|\downarrow_A>\right)(c|\uparrow_B> + d|\downarrow_B>)$ with constants a, b, c, d. Show that this leads to a contradiction in that no values of a, b, c, d can fulfill the resulting equations.