Underwater Quantum Adventure: Scavenger Hunt - Final Report

Introduction

Welcome to the final report of the Underwater Quantum Adventure: Scavenger Hunt. This report provides a detailed overview of the quantum puzzles presented in the game, including the questions, correct answers, and explanations. The aim of this game is to enhance the understanding of quantum mechanics concepts through interactive problem-solving.

Puzzle 1: The Coral Clusters

Question

You discovered three types of coral clusters labeled A, B, and C.

- Cluster A is in a pure state represented by $|\rangle = \frac{1}{\sqrt{3}}|0\rangle + \sqrt{\frac{2}{3}}|1\rangle$.
- Cluster B is in a mixed state with a 50% chance of being in $|0\rangle$ and 50% chance of being in $|1\rangle$.
- Cluster C is in a pure state represented by $|\rangle = \frac{1}{\sqrt{2}}(|0\rangle|1\rangle)$.

Fill in the corresponding density matrices for these states to unlock the code for the next clue.

Correct Answers

- **Density Matrix for Cluster A**:

$$\rho_A = \begin{pmatrix} 0.333333 & 0.471404 \\ 0.471404 & 0.666667 \end{pmatrix}$$

- **Density Matrix for Cluster B**:

$$\rho_B = \begin{pmatrix} 0.5 & 0.0 \\ 0.0 & 0.5 \end{pmatrix}$$

- **Density Matrix for Cluster C**:

$$\rho_C = \begin{pmatrix} 0.5 & -0.5 \\ -0.5 & 0.5 \end{pmatrix}$$

Explanation

- For Cluster A, the state is $|\rangle = \frac{1}{\sqrt{3}}|0\rangle + \sqrt{\frac{2}{3}}|1\rangle$. The density matrix is calculated as $\rho_A = |\rangle\langle|$.
- For Cluster B, the mixed state is equally likely to be $|0\rangle$ or $|1\rangle$, resulting in a density matrix

$$\rho_B = 0.5 \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} + 0.5 \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

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- For Cluster C, the state is $|\rangle = \frac{1}{\sqrt{2}}(|0\rangle|1\rangle)$. The density matrix is calculated as $\rho_C = |\rangle\langle|$.

Puzzle 2: The Sunken Ship

Question

You need to send a secure message to your teammate using the ancient encryption device. You have the following quantum states available to form your key: $|0\rangle$, $|1\rangle$, $|+\rangle$ (which is $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$), and $|\rangle$ (which is $\frac{1}{\sqrt{2}}(|0\rangle|1\rangle)$).

Which states would you use to maximize security against eavesdropping?

Correct Answer

The correct states are: $|0\rangle, |1\rangle, |+\rangle, |\rangle$.

Explanation

Using these states helps maximize security against eavesdropping based on the principles of Quantum Key Distribution (QKD). The superposition states $|+\rangle$ and $|\rangle$ provide additional security by making it harder for an eavesdropper to measure the state without being detected.

Puzzle 3: The Entangled Seaweed Forest

Question

In the seaweed forest, you encounter two entangled qubits represented by the state $|\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle)$.

If the first qubit is measured and found to be in the state $|1\rangle$, what state will the second qubit collapse into?

Correct Answer

The correct state is $|0\rangle$.

Explanation

For the entangled state $|\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle)$, if the first qubit is measured to be $|1\rangle$, the second qubit must collapse into the state $|0\rangle$ due to the entanglement.

Puzzle 4: The Echo Caves

Question

Using the instruments in the Echo Caves, you can change the angle settings for your quantum measurements. If you set the angles to 0, 45, and 90 degrees for three different measurements, predict whether these settings will violate Bell's inequality.

Correct Answer

- For 0 degrees: 1.0
- For 45 degrees: 0.707106
- For 90 degrees: 0.0

Explanation

The expected values are the cosine of the angles:

- $\cos(0°) = 1.0$
- $\cos(45°) = \frac{1}{\sqrt{2}} \approx 0.707106$
- $\cos(90°) = 0.0$

These values help determine if Bell's inequality is violated.

Puzzle 5: The Teleportation Trench

Question

You must teleport a quantum state $|\rangle = \frac{2}{3}|0\rangle + \sqrt{\frac{5}{3}}|1\rangle$ using the teleportation protocol. Given an entangled pair in the state $|^{+}\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$, describe the steps you would take to teleport $|\rangle$ from one location to another.

Correct Answer

1. Alice and Bob share an entangled pair in the state $|^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$.
2. Alice performs a Bell-state measurement on her qubit and the state $|\rangle$.
3. Alice sends the measurement result to Bob using classical communication.
4. Bob applies the appropriate quantum gate based on Alice's result to his qubit.
5. The state $|\rangle$ is now teleported to Bob's qubit.

Explanation

Quantum teleportation involves using an entangled pair and classical communication to transfer the state $|\rangle$ from Alice to Bob. Alice's Bell-state measurement and the subsequent classical communication allow Bob to apply the correct transformation to his qubit, resulting in the teleportation of $|\rangle$.

Puzzle 6: The Circuit Reef

Question

You are given a basic quantum circuit that includes two qubits initialized in the state $|0\rangle$ and $|1\rangle$. Use quantum gates available in the reef (represented by different species of fish) to create a circuit that performs the operation of a quantum half-adder.

Correct Answer

1. Apply a Hadamard gate to the first qubit.
2. Apply a CNOT gate with the first qubit as control and the second qubit as target.
3. Apply an additional gate to complete the half-adder circuit.

Explanation

A quantum half-adder can be implemented using a combination of quantum gates. The Hadamard gate creates a superposition on the first qubit, and the CNOT gate entangles the two qubits. An additional gate is used to complete the half-adder operation.

Puzzle 7: The Bloch Sphere Bubble

Question

Navigate the controls to align the qubit at the point representing the quantum state $|\rangle = \cos(\frac{}{2})|0\rangle + e^{i}\sin(\frac{}{2})|1\rangle$ with $= \frac{\pi}{3}$ and $= \frac{\pi}{4}$. Calculate the coordinates on the Bloch sphere where you should place the marker.

Correct Answer

- x : 0.612372
- y : 0.612372
- z : 0.5

Explanation

The coordinates on the Bloch sphere are calculated as follows:

- $x = \sin(\theta)\cos(\phi) = \sin(\frac{\pi}{3})\cos(\frac{\pi}{4}) = 0.612372$
- $y = \sin(\theta)\sin(\phi) = \sin(\frac{\pi}{3})\sin(\frac{\pi}{4}) = 0.612372$
- $z = \cos(\theta) = \cos(\frac{\pi}{3}) = 0.5$

Conclusion

Congratulations! You have completed the Underwater Quantum Adventure. This scavenger hunt aimed to enhance understanding of various quantum mechanics concepts through interactive problem-solving. We hope you enjoyed this educational journey through the underwater quantum world.