

Decoherence, noise, and mitigation

Open-system evolution and the limits of controlling real quantum systems.

THE CENTRAL QUESTION

What happens to locally observable information when a system couples to an environment?

Entanglement with unobserved degrees of freedom can turn coherent local evolution into decoherence.

Prediction: state what should change in the first experiment and what must remain invariant.

KEY TERMS

open system
partial trace
quantum channel
decoherence

MODEL

$$\rho_S' = \text{Tr}_E[U (\rho_S \otimes \rho_E) U^\dagger]$$

FIRST WORKED EXPERIMENT

Start with one case small enough to check by hand.

1. Write the input and prediction
2. Apply the operation
3. Compare the observed evidence

Evidence to keep: reduced density matrix, off-diagonal norm, purity, and entropy. Label basis order, shots, and simulator assumptions.

EXPERIMENT

Entangle a qubit with an environment qubit and track local coherence as coupling grows.

THE CENTRAL QUESTION

Which observed errors come from the state, gates, measurement, or environment?

A useful mitigation claim begins with a declared noise model and a metric measured against an ideal baseline.

Prediction: state what should change in the first experiment and what must remain invariant.

KEY TERMS

depolarising channel
amplitude damping
readout error
mitigation

MODEL

noisy output = channel(ideal circuit state)
plus measurement effects

FIRST WORKED EXPERIMENT

Start with one case small enough to check by hand.

1. Write the input and prediction
2. Apply the operation
3. Compare the observed evidence

Evidence to keep: bias, variance, circuit cost, and failure outside the calibration range. Label basis order, shots, and simulator assumptions.

EXPERIMENT

Sweep one noise parameter and compare raw, mitigated, and ideal expectation values.

A physical decoherence mechanism

Develop one system–environment coupling model. Calculate the reduced state and the loss of off-diagonal coherence.

Distinguish decoherence, measurement conditioning, relaxation, and dephasing.

Noise channels and time scales

Introduce T_1 and T_2 with physical preparation and readout procedures.

Work through a simple channel and compare ideal and noisy output probabilities.

Error mitigation and its limits

Choose a mitigation method and state its calibration assumptions.

Compare bias, variance, and sampling overhead. Explain why mitigation alone does not provide fault tolerance.