

Claims:

1. A quantum computer comprising:
 - an apparatus having one or more atomic objects therein;
 - 5 a first manipulation source configured to provide a first manipulation signal;
 - a second manipulation source configured to provide a second manipulation signal;
 - and
 - a controller, the controller configured to:
 - cause the first manipulation source to provide the first manipulation signal to a
 - 10 particular region of the apparatus, wherein the first manipulation signal is tuned to excite atomic objects within the particular region of the apparatus that have leaked out of a qubit space from a leaked state to an intermediary manifold and to suppress excitation of atomic objects that are in the qubit space, wherein the qubit space is defined in a ground state manifold of the one or more atomic objects, the leaked state is in the ground state manifold,
 - 15 the ground state manifold is a $^2S_{1/2}$ manifold, and the intermediary manifold is a $^2D_{3/2}$ manifold; and
 - cause the second manipulation source to provide the second manipulation signal to the particular region of the apparatus, wherein (a) the second manipulation signal is tuned to excite atomic objects from the intermediary manifold to a decay manifold and (b) there is a
 - 20 non-zero probability that an atomic object will decay from the decay manifold into the qubit space, wherein the decay manifold is one of a $^2P_{1/2}$ manifold or a $^3[3/2]_{1/2}$ manifold.
2. The quantum computer of claim 1, wherein the controller is configured to cause the first and second manipulation sources to sequentially provide the first and second
- 25 manipulation signals a plurality of times to achieve a desired leakage suppression factor, wherein after the second manipulation source provides the second manipulation signal, the controller causes the first manipulation source to provide another first manipulation signal after a decay time.
- 30 3. The quantum computer of claim 2, wherein the decay time is determined based on a time for an atomic object to decay from the decay manifold to a ground state manifold, the qubit space being defined within the ground state manifold.

4. The quantum computer of claim 1, wherein the qubit space is defined based on hyperfine structure of a ground state manifold of the one or more atomic objects.
5. The quantum computer of claim 1, wherein the first manipulation signal is shaped to suppress transitions out of the qubit space.
6. The quantum computer of claim 1, wherein the first manipulation signal is tuned to excite a quadrupole transition from the leaked state to the intermediary manifold.
- 10 7. The quantum computer of claim 1, wherein excitation of atomic objects that are within the qubit space is suppressed by high magnetic fields which cause large energy detunings for unwanted transitions.
- 15 8. The quantum computer of claim 1, wherein the wave vector and polarization of the first manipulation signal are arranged to minimize excitations of atomic objects out of the qubit space.
9. The quantum computer of claim 1, wherein the one or more atomic objects are nuclear-spin $\frac{1}{2}$ atomic objects.
- 20 10. The quantum computer of claim 1, wherein a wave vector and a polarization of the first manipulation signal are substantially orthogonal to a magnetic field in the particular region of the apparatus.
- 25 11. A method for suppressing leakage error in a quantum computer, the method comprising:
causing, by a controller of the quantum computer, a first manipulation source to provide a first manipulation signal to a particular region of an apparatus of the quantum computer having one or more atomic objects therein, wherein the first manipulation signal is
30 tuned to excite the one or more atomic objects within the particular region of the apparatus that have leaked out of a qubit space from a leaked state to an intermediary manifold and to suppress excitation of atomic objects within the particular region of the apparatus that are in the qubit space, wherein the qubit space is defined in a ground state manifold of the one or more atomic objects, the leaked state is in the ground state manifold, the ground state
35 manifold is a $^2S_{1/2}$ manifold, and the intermediary manifold is a $^2D_{3/2}$ manifold; and

causing, by the controller, a second manipulation source to provide a second manipulation signal to the particular region of the apparatus, wherein (a) the second manipulation signal is tuned to excite atomic objects from the intermediary manifold to a decay manifold and (b) there is a non-zero probability that an atomic object will decay from the decay manifold into the qubit space, wherein the decay manifold is one of a $^2P_{1/2}$ manifold or a $^3[3/2]_{1/2}$ manifold.

12. The method of claim 11, further comprising causing, by the controller, the first and second manipulation sources to sequentially provide the first and second manipulation signals a plurality of times to achieve a desired leakage suppression factor, wherein after the second manipulation source provides the second manipulation signal, the controller causes the first manipulation source to provide another first manipulation signal after a decay time.

13. The method of claim 12, wherein the decay time is determined based on an average time for an atomic object to decay from the decay manifold to a ground state manifold, the qubit space being defined within the ground state manifold.

14. The method of claim 11, wherein the qubit space is defined based on hyperfine structure of a ground state manifold of the one or more atomic objects.

15. The method of claim 11, wherein the first manipulation signal is shaped to suppress transitions out of the qubit space.

16. The method of claim 11, wherein the first manipulation signal is tuned to excite a quadrupole transition from the leaked state to the intermediary manifold.

17. The method of claim 11, wherein excitation of atomic objects that are within the qubit space is suppressed by high magnetic fields which cause large energy detunings for unwanted transitions.

18. The method of claim 11, wherein the wave vector and polarization of the first manipulation signal are arranged to minimize excitations of atomic objects in the qubit space.

19. The method of claim 11, wherein the one or more atomic objects are nuclear-spin $\frac{1}{2}$ atomic objects.

20. The method of claim 11, wherein a wave vector and a polarization of the first
5 manipulation signal are substantially orthogonal to a magnetic field in the particular region of the apparatus.