Quantum computing with trapped ions, atoms and light

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We consider current experimental achievements relevent to quantum information physics, and discuss the best way to achieve the essential requirements of reliable quantum memory, gate operations, and read-out. We argue on general grounds for the attractiveness of nuclear spins as qubits, and light for the coupling required for quantum gates. We then consider the major limitations and prospects for realising quantum computing via quantum optics methods, that is, trapped atoms or ions interacting with light. There is always a trade-off between speed and precision of the quantum gates. We identify this trade-off for two specific cases, namely the Cirac-Zoller proposal [1] in which gates are achieved by exciting vibrational modes of trapped ions, and a cavity QED method using adiabatic passage which may be realised for ions or neutral atoms in a small high-Q cavity [2]. The Cirac-Zoller approach needs to be carefully adapted to allow the fastest possible gates [3,4]. It then emerges that with current technology, these two approaches have a similar speed, but there is more room for improvement in the cavity QED method if technological development continues [5].

It is likely that a single ion trap will not in itself allow a large quantum computer to be realised. However, the concept of linking ion traps via cavity QED methods is sufficiently well understood and promising to merit serious experimental and theoretical attention. By making a detailed analysis of fault-tolerant methods based on quantum error correcting codes [6], it is possible to estimate the size and precision of a quantum processing system which would be needed to run a fairly large quantum algorithm, such as 10^6 Toffoli gates on 100 logical qubits. It emerges that around 200 ion traps, linked by high-finesse cavities and optical fibres, could perform such an algorithm, though the precision requirement makes the system run slowly, taking of order several weeks to complete the task. This estimate is based on a cautious analysis, it may be possible to run significantly faster.

The main conclusion is that experiments and theoretical concepts in this area have a long way to go before they run out of possibilties. More generally, it is clear that both the speed and the precision need to be taken into account when contemplating possibilities for quantum computing.

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