1.5 Experimental quantum information processing

1.5.1 The Stern–Gerlach experiment

SG–experiment provides the evidence for the existence of qubit structure in Nature, that is, two level Q system.

Conceived by Stern in 1921 & performed by Gerlach in 1922.

Hot silver atoms were beamed from an oven through a B-field : The original exp.
Hot hydrogen atoms are : Abstract schematic exp

A continuous distribution of atoms at all angles from the SG device was expected: the atoms are deflected by an amount that depends on atom's m_z (the orig. exp.)

m is quantized : Atoms were emerged to a discrete set of angles.

m_z of hydrogen atom related to orbital angular momentum = 0. Only 1 beam of atoms, No deflection was expected

Instead, Two beams were seen : One is deflected up by the B field, the other is down.

This puzzling doubling was explained by considering *spin*

- Not in any way associated to the usual rot motion of the el around the proton.
- An entirely new quantity to be associated with an electron.
- make an extra contribution to the m of a H-atom.

```
+---------+              +---------+
|         |              |         | -------> |+Z>
|   oven  |------------->|    Z    |
|         |              |         | -------> |-Z>
+---------+              +---------+
```

```
+---------+      +---------+   |+Z>    +---------+  |+X>  +---------+
|         |      |         | ------->  |         |------->|         |---> |+Z>
|   oven  |----->|    Z    |           |    X    |        |    Z    |
|         |      |         | -->[]     |         |-->[]   |         |---> |-Z>
+---------+      +---------+   |-Z>    +---------+  |-X>  +---------+
```

Fig. 1.22   Fig. 1.24.

qubit model provides a simple explanation of this experimentally observed behavior. predicts results from the cascaded SG-exp.

qubit could be a believable way of modeling sys in Nature. turned out to be a correct way of understanding el spin.

1.5.2 Prospects for practical quantum information processing

Will we rise to meet the challenge, building quantum information devices?
It is possible at all?
Is it worth attempting?
Whether there is any point of principle that prohibits us from doing Q-information processing?
Two possibilities:

1. Noise may place a fundamental barrier to useful Q-inf processing.
2. QM may fail to be correct.

For noise, Q error-correction theory strongly suggests that
while Q noise is a practical problem that needs to be addressed,
it does not present a fundamental problem of principle

Threshold Theorem :

- If the level of noise in a Q-computer can be reduced below a certain const threshold value,
  Q error correcting codes can be used to push it down even further,
  essentially *ad infinitum*, for a small overhead in the complexity of the computation
- Threshold Theorem makes some broad assumptions about the nature & magnitude of the noise occuring in a Q computer & the architecture available for performing Q-computation.
- If the assumptions are satisfied, the effect of noise can be made essentially negligible for Q information processing.

We assume that QM is a complete & correct description of the world.

There's no fundamental obstacle to building quantum information processing devices.

However, It is fair to say that a clearer picture of the relative power of quantum and classical information processing is needed in order to assess their relative merits

Many small scale applications on Q-computation & Q-information are known.

- Q state tomography & Q process tomography are two elementary process whose perfection is of great importance to Q-computation & Q-information.
  - Q state tomography : A method for determining the Q state of a sys.
    The hidden nature of the Q-state has to be overcome by performing repeated preparations of the same description of the Q-state.
  - Q process tomography : Intend to completely characterize the dynamics of a Q-system.
    can be used to characterize the performance of an alleged Q gate or Q comm channel, or to determine the types & magnitudes of different noise process in a sys.
- Q cryptography is likely to be useful in practical applications involving the distribution of small amount of key material that needs to be highly secure.
- Q teleportation may be an extremely useful primitive for transmitting Q-states between distant nodes in a network.
  Distributing EPRs between the nodes has been focussed.
  Special entanglement distillation protocols can be used to clean up the EPR pairs which was corrupted during communication enables EPR pairs to be used to teleport Q-sts from one location to another.
- Other applications, like quantum game theory, quantum walk and so on, are considered in terms of quantum communications.

medium scale application of Q-information processing.

The simulation of Q sys

eg) 50 qubit $2^{50} \cong 10^{15}$ complex amplitudes 32×10^{15} bytes need 32 bytes in order to store each amplitude for 128 bit precision. 32 thousand terabytes of information : well beyond the capacity of existing computer.

- elementary properties of materials(bond strength, basic spectroscopic properties)
- A lab for the design & testing of properties of novel molecules.

Large scale application : the factoring of large #s & taking discrete logarithm, Q searching

How can it be achieved in real sys?

- Optical technique : EM radiation
  - Producing a single photon on demand is a major difficulty.
  - Physicists opt to use schemes which produce single photons every ‘now and then’, at random, & wait for such an event to occur.

  - Major advantage : Photon tend to be highly stable carriers of quantum mechanical informations.
  - Major disadvantage :
    * Photon don't directly interact with one another.
    * Interaction has to be mediated by something else, like atoms, which introduction of additional noise & complications into the exp.

- Ion trap : a small # of charged atoms are trapped in a confined space. Neutral atom traps : trap uncharged atoms in a confined space.

- NMR Nuclear Magnetic Resonance : store Q information in the nuclear spin of atoms in a molecule & manipulate that information using EM radiation.

- other techniques of nano technologies like SQUID(josephson junction), fabricated magnetic materials, quantum well, quantum dot, quantum wire etc.