Feasibility Of Communications Using Quantum Correlations

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Potential Advantages of Communications Using QM Correlations

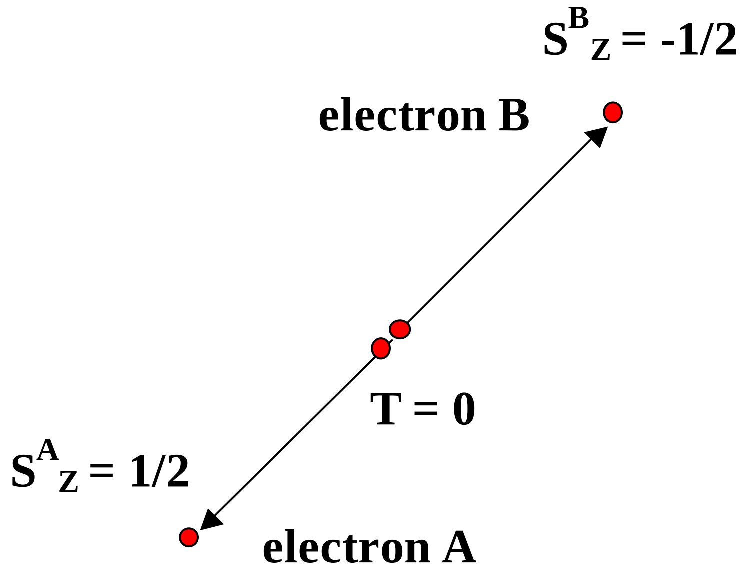
- No antenna needed, no broadcast power
- Very secure with high data rates
- Not line-of-sight
- No interference due to intervening medium
- No limitation on distance
- Faster than light??? Causality???

Quantum Correlations or Entanglement

- An entangled system consists of two or more quantum objects (atoms, photons etc) each of which carries information about the other.
- A single wavefunction characterizes the state of the system and is not a product of wave functions for each element of the system.
- The entire system cannot be analyzed as separate subsystems. In quantum mechanics there is no reality to the separate subsystems or objects.
- The entanglement persists no matter how far apart the atoms become, as long as the quantum state is unchanged.

Einstein-Podolsky-Rosen (EPR)-Bohm-Aharonov Gedanken Experiment

- Two electrons are in a S=0 state (zero total spin)
- At T=0, the electrons fly apart from each other
- The total spin remains zero
- Measurements of the spins are correlated so the total measured spin Sz is always 0, for any z, chosen at any time



$S_Z = S^A_Z + S^B_Z =$

Results of Recent Experiments With Entangled States

- Verified non-local quantum mechanical correlations in polarization of photons

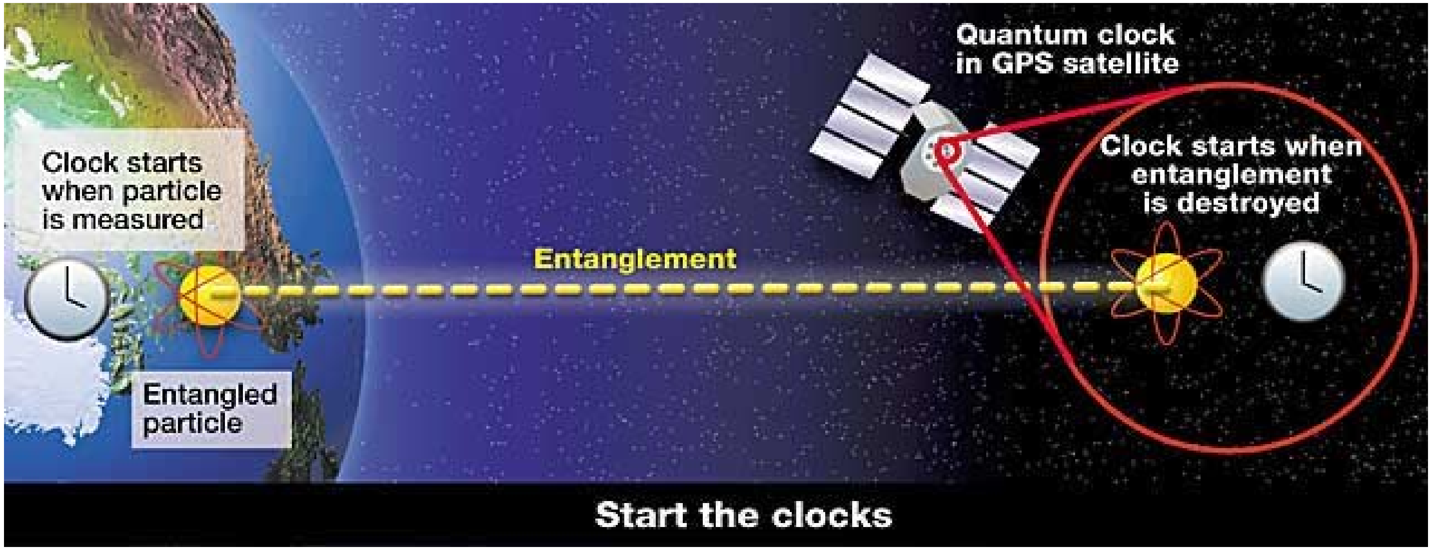
  (total spin = 0) over distances up to 10 km
- Verified continuous correlations in components of entangled electric fields
- The measurement on one entangled object affects the outcome of the measurement on the other distant object (non-local phenomena, yet no known violations of relativity)
- Very small possibility that experimental errors are the source of the measured non-locality

Can We Use QM Correlations for Communications?

- THEORETICAL RESTRICTIONS: current theory says we can't use just correlations in polarization of photons or electrons, and severely restricts other methods and FTL signals
- POSSIBILITIES: current theory may not prohibit use of non-local correlations in some approaches, for example if a classical channel also is used (quantum teleportation)

Use of Entangled States to Synchronize Satellite Clocks

- Entangled atoms are put in time invariant singlet state; atoms are then separated
- Do a “measurement” to end entanglement and start both atomic clocks operating



Method just proposed by researchers at JPL and Univ. of Bristol, England. Figure from New Scientist May 13, 2000. Ref: e-print quant-ph/0004105 at xxx.lanl.gov.

Technological Developments That May Enable Communications Using only Entangled States

- New techniques for generating and manipulating entangled atoms and ions
- More precise methods in EPR type experiments, indicating non-local correlations
- New measurement methods in quantum mechanics, such as "protective measurements"

Using Entangled Photons or Electrons for Communication
I. The Attempt

- Assume you want to make a communication link using EPR pairs, labeled A and B
- Measuring the spin of particle A in the z-direction will put the spin of A in the z-direction and, by entanglement, will do the same for B
- Assume putting spin of A in z-direction transmits a “0” and in the y-direction transmits a “1”
- But does this communicate??

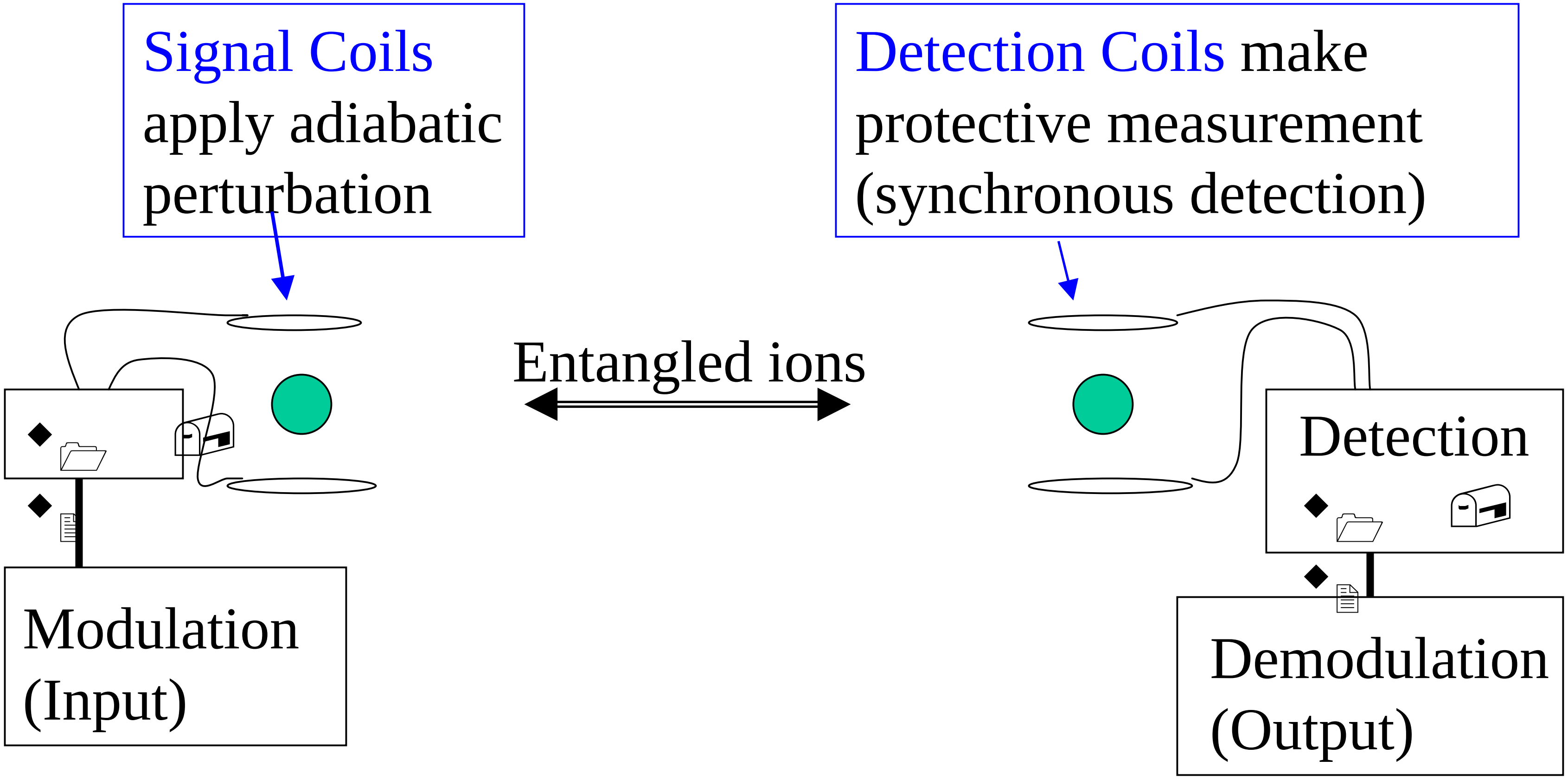
Using Entangled Photons or Electrons for Communication
II. Technical Problems

- ANY spin measurement on B or any electron or photon puts the particle in a spin eigenstate and gives a binary (dichotomic) result (e.g.for electron + ½ or – ½)
- ANY spin measurement on B ends the entanglement with A so a second measurement gives no more information
- Not enough information is obtained from the measurement on B to determine the polarization axis used in the measurement on A (no internal standard)

Proposed Approach to Communication Using Entangled States

- Use long lived atomic or ionic states with the "right" kind of entanglement (e.g. continuous, boson…?)
- Avoid the use of a conventional measurement, which necessarily changes the state, ending the entanglement and any potential communications link.
- Perform an adiabatic perturbation ("input signal") on particle A which does not change the state or the entanglement (to first order in perturbation theory).
- Detect a correlated modulation in particle B using a "protective measurement," which does not change the state of the system or the entanglement. Ref. for protective measurement:Aharanov, Anandan, and Vaidman, Phys. Rev. A 47, p. 4616(1993)

Schematic of Communications System using Entangled Ions



EPR Experiments and The Causal Interpretation of QM by Bohm

- Causal model predicts same EPR measurements as QM but also gives a continuous description of the evolution of the system between measurements
- Causal model has a non-local quantum potential and torque
- In EPR experiment, in which one electron passes through a Stern-Gerlach magnetic field in the z-direction, the z-component of the spin of the other electron rotates continuously so the spin is always the opposite ($S^A{}_z + S^B{}_z = 0$)

Communications System Challenges and Requirements

- Need to maintain entanglement while particles are separated and minimize decoherence due to environmental effects (isolation)
- Need to develop modulation and detection methods that maintain the entanglement while perturbing one atom enough to be able to detect the correlated response in the other entangled particle
- Some methods may be impossible because they violate known or unknown laws of physics
- Atomic energy levels spaced to give a stable system and good bandwidth

REGIONS OF QUANTUM CORRELATIONS

STRENGTH OF PERTURBATION

SEPARATION "D" BETWEEN MEMBERS OF AN EPR PAIR

ANGSTROMS — CM — KM — PARSEC

STRONG
(COLLAPSE OF WAVEFUNCTION)

MODERATE

WEAK

CORRELATION VERIFIED EXPERIMENTALLY IN THIS REGION

CORRELATION STRONGLY EXPECTED IN THIS REGION **(TO BE VERIFED BY THEORY IN PHASE I)**

AREA TO RESEARCH **(PHASE I/THEORY) (PHASE 2/EXPT.)**

DO CORRELATIONS EXIST IN THIS REGION??

?????????????????????

NIAC REGION OF INTEREST

Proposed Approach

- Develop a model system based on recent ion manipulation research: ions in harmonic potentials
- Analyze effects of perturbations, and ordinary and protective measurements on entanglement
- Do theoretical study of the effects of entanglement as a function of separation between the ions
- Identify critical experiments (and theory) that would determine if communications using entanglement is possible or impossible

Thanks to NIAC
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