Quantum Institute Workshop

Quantum Institute Briefing Center; December 9–10, 2002

Proposed Breakout groupings:

1. AMO (atomic, molecular, and optical) working group—atom, ion, molecular, and optical based experiments and theory
2. Condensed matter working group—spin and exciton based experiments and theory (Si-based, NMR, colloidal quantum dots)
3. Stand alone theory working group—foundations of QM, fundamental quantum information theory, algorithms and quantum simulation (all overarching theory not tied to a specific experimental method mentioned above)

Questions to discuss in breakout groups:

1. What are the common themes and the focus areas of this topic?
2. What opportunities can go after (both in the fundamental and applied research areas)?
3. What strengths (or uniqueness) differentiate us from the rest of the national and international competition?
4. What existing relationships (both basic research and programmatic) within the Lab and with outside collaborations make us strong, and how could the QI best foster the development of future collaborations?
5. Where do we have gaps in our capabilities, and what are our weaknesses? Do we need to address them to make the QI a success?

Condensed matter working group breakout session

Toni Taylor (chair), Gennady Berman, Geoff Brown, Holger Grube, Salman Habib, Daniel James, Victor Klimov, Ivar Martin, Dima Mozyrsky, Stuart Trugman

Goals

Prepare, manipulate and measure quantum state.

QC approaches in solid state at LANL

Prepare qubits and address scaleability

Exciton Based

1. Semiconductor quantum dots
   - Atomic-like quantum state
2. Exciton based in semiconductor quantum dots
   - Colloidal
   - MBE

Spin Systems

1. Isolated spins in bulk solids (e.g. phosphorus donors in silicon quantum computer)
2. Magnetic quantum dots
   - Dots in bulk
   - Dots doped with Mg
3. Optically excited

Quantum Control

Control coupling of quantum systems

- dipole-dipole
- phonon
- modes of microcavity
- exchange coupling

Readout, communication, information processing of quantum systems

Controlling collective quantum states in bulk solids

Bulk states

Nanomechanics

Novel Nanoscale Measurement Techniques

Quantum limits on measurement

FET-based spin detection

STM-based spin detection

NSOM (ultrafast, spectroscopy)

Single dot Kerr-based, fluorescence (time resolved)

Ultrafast STM

Inelastic STM

Near field THz spectroscopy

MRFM

Nanomechanics

Nanofabrication

STM-based □ Quantum dot, wires, and Quantum neural technology

Epitaxial

Colloidal

Ion beam

Collaborations

CINT (LANL/Sandia)

Spintronics

QD NSET-BES

NHMFL/LANSCE

Supercomputing

AMO Quantum I Theory

Efros, Chris Hammel, Heath, Awschalom, Michael Roukes, Keith Schwab, H. W. Jiang, Yablonovitch, Robert Clark, Reitze, Sherwin, CHTM

Strengths

Strong experimental/theoretical effort in:

- Novel probes
- Quantum dot physics and chemistry
- Spintronics
- NHMFL, LANSCE,
  Supercomputing

CINT

Reputation in condensed matter physics

Integrated effort not possible in university

Gaps

Disconnect between experiment and theory?

Theory of semiconductor quantum dots

Fabrication gap → CINT help

Characterization (TEM) → CINT

Opportunities

BES → AMO → NSET → materials

DARPA → spintronics

NSA, ARDA, LDRD, ONR

Question 1: Focus Areas
AMO – Quantum Manipulation

ATOMS	DEVELOPMENT LEVEL	FUNDAMENTAL or APPLIED
Ultra-sensitive DETECTION (USD)	Adv.	Applied
BEC/Fermions	Med-experiment Adv.-theory	Fundamental
Spin-entangled atoms	New	Fund/Applied
BEC/atom optics	Med	Fund & Applied
Sr	Med	Fund & Applied
Slowlight	Adv theory	both
Quantum control	Adv theory	both
Photons		
QKD	Advanced	applied
Quantum communications	Medium	both
Quantum imaging/metrology	New	both
Molecules		
Cooling/Trapping	New	both

Question 2: Opportunities
Intel connection can grow
Office of Science
 Eric Rohlfing
 Advance a **few**, well-polished proposals for **individual** projects

LDRD
 Help coordinate a few DR proposals
  (focused, with QI "flag")

NIS Division – closer contacts

Opportunities for students
 Exchange students
 "QI" students
 "QI" postdocs – joint sponsorship
  intel community and National Security postdocs
  foster/create/formalize relationship of QI with:
  UNM, UC campuses

Question 3: Strengths/differentiation
Broad expertise and capabilities
- cutting-edge research
- integration: basic and applied and classified

Aligned with National Security Mission
- Strong customer connection

Strong and diverse theory
- decoherence theory; superfluidity; non-linear physics
- quantum control; quantum optics

Capabilities
- Ultra-low light level detection
- Trapping/cooling atoms/molecules
  - Radioactive atom trapping
- Advanced sensors
- HPC

Question 4: relationships; role of QI

Many National/international collaborations

Strong **technical** relations with sponsors

How will QI help develop future collaborations?
- QI as a focal point
- Increase communication/collaborations with Lab
- Common focus within Lab for field

Increase visibility outside Lab: QI is "THE" place

Selling projects
- Open doors, improve proposals
- Distribute calls for proposals

Lab needs to support: **modest**
- Visitor program
- Exchange student and "QI" postdocs/students
- Web page and briefing center
- Good lab space and support
- POC for QI (admin)

Question 5: gaps and weaknesses

Experimental groups too small
- Recruit students, postdocs, staff to strengthen

Program development resources
- Coordinated IPD
- Division PD $TP
- PD $

Themes	Exceptional Strengths	Connection to DOE
Decoherence	✓✓	✓
Entanglement	✓	✓
Quantum measurement		
Quantum control	✓	✓
Quantum computing —theory, digital, neural		✓
Quantum algorithms		
Quantum noise control and error correction	✓✓	
Quantum communication and cryptography		
Quantum complexity		
Information view of physics	✓✓	
Quantum chaos		✓
Quantum-classical transition	✓✓	✓
Implementations	✓	

Funding Opportunities

- LDRD
- X-Div and NIS
- DOE (BES, NNSA, HPC. . .)
  Quantum simulations of interest to DOE, X-Div
- DARPA
- ONR
- AFOSR (Air Force)
  Type II quantum computers
- NSA
- ARDA
- Industrial connections?
- UNM←NSF?

Strengths

- Diversity/breadth
- Strength in numbers
- History of seminal contributions
- Reputation

- Interaction with experimentalists, internal and external
- Ability to do big projects
- Ability to do classified research

Existing Collaborations

- Internal
    - Experimental: MST, P, C, B
    - Theory: CCS, T, C, NIS
- External
    - The usual suspects: CalTech, MIT, U of Texas, **UNM**, UCB, UIUC, **Perimeter**, Ecole Normal, UNSW, U Buenos Aires, Cornell, **U California** (**bold** means we should grow the connection)

Gaps

- Retention problems (and gaps resulting from it)
  resolution partially depends on solution to funding instabilities
- Perception of the lack of sufficient support
- Funding instability
  get DOE on board
- Lack of communication
  being addressed, e.g. visitor program