

Interactions

Department of Physics and Physical Oceanography Newsletter

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Quantum Cloning and Quantum Information Research at UNCW

By Professor Moorad Alexanian

The development of high speed modern computers has given rise to miniaturization of computer chips. Further improvements in speed and size are expected to lead to “ultrasmall” systems where the quantum nature of matter will definitely come into play. Chipmakers are already relying on nanotechnology in their designs.



Dr. Moorad Alexanian

Theories describing quantum systems are studied by simulations on computers that are actually based on classical principles. However, the complexity of quantum systems makes such computational studies rather difficult and time consuming. Richard Feynman pointed out in 1982 that building computers based on the basic principles of quantum mechanics may make the studies of real, quantum systems feasible.

Classical computers manipulate and interpret binary bits. A bit is the basic unit of information and is represented by a 0 or a 1. In a classical computer a bit is typically stored in a silicone chip, a metal hard drive platter, or on a magnetic tape. About 10^5 atoms are currently used to represent one bit of classical information.

In a quantum computer, on the other hand, the fundamental unit of information is the quantum bit (qubit), which is characterized by the two possible states of a quantum mechanical system. Examples are the two spin states of a spin-1/2 particle, the two polarization states of a transverse photon, the zero-photon (the vacuum) and the one-photon states of a quantized electromagnetic field, an atomic two-level system with a ground state and an excited electronic state, etc.

In work done in cooperation with Dr. Subir Bose of the University of Central Florida, we studied the time evolution of initially pure disentangled atom-field states under the action of two-photon processes¹. If the photonic part of the disentangled state is a superposition of a squeezed vacuum and the *odd* photonic state, a new quantum

photonic state introduced in our work, then the composite system undergoes cycles of entanglement with

Notes from the Chair



Dr. Curt Moyer

With this issue of Interactions, we mark another turning point in the brief history of our newsletter. We previous installments have been distributed in the spring, future issues will now appear in January of each year. Furthermore, in a cost-cutting move we will no longer be mailing print copies; instead each issue beginning with the current one will be posted in portable document format (pdf) to the Department web site at <http://www.uncw.edu/phy>.

Since our last newsletter in April 2003, there have been several events that have brought increased recognition to the Department of Physics and Physical Oceanography and bolstered its position as an emerging force, both at UNCW and beyond.

For Fall 2003 and again in 2004, Professor Fred Bingham taught PHY 105 (Introductory Physics) as part of a UNCW Learning Community (LC) with Professor Paul Townend of the History Department. The LC titled "Science, Technology and Western Civilization" included discussion of the lives of great physicists and how their discoveries influenced the times in which they lived. The LC experience is new to UNCW, and we can take pride that the Department is already a player in this high-profile venture.

The total number of undergraduate physics majors now stands at about 24, up slightly from a year ago and a dramatic turnaround from the low of 14 reported in 2001-2002. One result of this growth – or possibly the cause of it – is that student involvement in faculty-directed research has reached an all time high, with 8 students participating in 6 different projects during the 2003-2004 academic year. DIS activities have led to oral presentations by our undergraduate majors in several different venues: departmental colloquia, the 70th Annual SESAPS Conference (more on that below), the Triangle Undergraduate Research Symposium held at Duke University, and the 2004 CAA Undergraduate Research Conference held at the University of Delaware.

In November 2003, the Department was privileged to host the 70th Annual Meeting of the Southeastern Section of the American Physical Society (SESAPS). The conference took place at the Holiday Inn Sunspree, Wrightsville Beach. With 243 registered participants including 75 undergraduate students from colleges and universities throughout the southeast, this was among the largest meetings in the history of the organization. The event was marked by several 'firsts', including the first joint meeting with the NC-AAPT (North Carolina Section of the American Physical Society), and the first time a SESAPS gathering was hosted by such a small department. Special thanks are due Professors Moorad Alexanian who chaired the Local Organizing Committee, Liping Gan who organized two focus sessions on Quantum Chromodynamics (QCD) and chaired one of them, and Timothy Black who organized and participated in the SPS multi-zone meeting, organized a student poster session and competition for the Marsh White Award, and chaired one of the two SESAPS conference sessions on Nuclear Physics.

One immediate benefit of hosting SESAPS was the complete renovation of the DL 212 lecture facility, the site of the 2003 SPS multi-zone meeting. The makeover included a fresh coat of paint, new carpet and flooring tiles, refinished desktops, and a custom-built demonstration and storage console.

We close the 2004 calendar year with a nationwide search for another physical oceanographer well underway, as the Department seeks to strengthen its ties with the UNCW Center for Marine Science and broaden its undergraduate course offerings. Can an M.S. degree program in physics be far behind...?

Faculty Update

Three physics faculty were invited to present the results of their research to international audiences: **Dr. Moorad Alexanian** spoke at the Symmetries in Science XIII symposium held at the Kloster Mehrerau, Bregenz, Austria, in June 2003. The title of his talk was “*The No-cloning Theorem.*” Symposium proceedings were published by Kluwer Academic Publishers. **Dr. Timothy Black** gave a seminar to the Fourth International Workshop on Chiral Dynamics 2003, Rheinische Friedrich-Wilhelms-Universität, Bonn, Germany, September 2003. The title of his presentation was “*Some New Experimental Results in the Three and Four Nucleon System*”. They were joined by **Dr. Liping Gan**, who spoke on “*Chiral Symmetry and Electromagnetic Properties of Pseudoscalar Mesons*” at the International Conference on Physics Education and Frontier Research, in Shanghai, China, June 2004.

Dr. Liping Gan has been reappointed to a second three-year term as Assistant Professor, effective August 2004. In making its recommendation, the Faculty Committee on Reappointment, Promotion, and Tenure cited her “outstanding publishing and research funding record”, describing her accomplishments over the first three years here as “exceptional”.

The Coastal Ocean Research and Monitoring Program (CORMP), under the capable direction of **Dr. Marvin Moss**, is the beneficiary of another \$2,325,084 in support from the National Oceanic and Atmospheric Association (NOAA). This marks the third consecutive year that NOAA has contributed substantial funds toward this effort. Dr. Moss also received an additional \$82,921 from NOAA/Commerce to integrate CORMP into a nationwide observing network in a project titled “*Building the Integrated Ocean Observing System: Integrating the Coastal Ocean Research and Monitoring Program (CORMP) with Regional and National Observing, Data and Governance Systems and Structures*”.

Faculty

2004-2005

*Moorad Alexanian, Professor
Ph.D. Indiana University*

*Frederick M. Bingham
Associate Professor
Ph.D. University of California, San Diego*

*Timothy C. Black, Assistant Professor
Ph.D. UNC Chapel Hill*

*Brian F. Davis, Professor
Ph.D. NC State University*

*Liping Gan, Assistant Professor
Ph.D. University of Manitoba*

*Marvin K. Moss, Professor
Ph.D. NC State University*

*Curt A. Moyer, Professor
Ph.D. SUNY, Stony Brook*

*Edward A. Olszewski Jr.
Professor
Ph.D. UNC Chapel Hill*

machine, which can be viewed as the continuous counterpart of the universal qubit cloner, the two outputs are a mixture of coherent states characterized by a density matrix with fidelity $2/3$. On the other hand, the cloner proposed gives rise to two identical, pure coherent states as output. This cloning machine is a “universal cloning machine” for coherent states since the cloning process is input independent.

The no-cloning theorem for pure states has been generalized and extended to the case of mixed states. The notion of broadcast is introduced to include the possibility that although an arbitrary mixed state may not be cloned nevertheless it may be marginally reproduced. Thus cloning of mixed states would represent a strong form of broadcasting. It should be remarked that the notion of cloning or broadcasting considered refers to the case where the cloned or broadcasted output are precisely the same as the input state to be cloned or broadcasted.

Recently we extended the notion of cloning to mixed states³. The notion of broadcasting is extended to include the case where an arbitrary input density state of a two-mode radiation field gives rise to an output state with identical marginal states for the respective modes, albeit different from the input state. The initial unknown input density state is unitarily related to the output state but is not equal to the two identical output marginal states. This extended notion of broadcasting suggests a possible way of discriminating between two noncommuting quantum

states.

In closing, the no-cloning theorem and the no-broadcasting theorem impose fundamental quantum mechanical restrictions on the ability to copy or broadcast arbitrary states. Both theorems are combined into one by proving that noncommuting mixed states cannot be broadcast and that cloning represents a strong form of broadcasting. In our work², the cloning of coherent states by a cavity-cloning machine suggests a weaker operational definition of cloning or copying. The cloning machine produces two identical pure states as output that are unitarily related to a different input state. In previous works, the input and the two output states are required to be identical.

In our latest work³, the meaning of broadcasting is weakened to mean that the output density state for the two-mode radiation field are in the same marginal state, which differs from the input state but is obtained from it by a unitary transformation. Other more modest, operational definitions of a quantum copier have also been considered previously. The ability of the unambiguous discrimination of two mixed states ought to be of interest in quantum cryptography where the usual procedure is to encode information into noncommuting mixed states in order to prevent eavesdropping.

References

- ¹ M. Alexanian and Subir K. Bose, Phys. Rev. A 65, 033819 (2002).
- ² M. Alexanian, Phys. Rev. A 67, 033809 (2003).
- ³ M. Alexanian, arXiv.org:quant-ph/0409105 v1

Would you like to support The Department of Physics and Physical Oceanography with a donation? It is with your help that we can provide a meaningful education for UNCW physics students. **Thank you for your support!**

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ATTENTION ALUMNI

We want to hear from you!

Please send any information about yourself, such as graduation, marriage and birth announcements, what you are doing in school or in your career, where you are living, anything you would like to share with the rest of the UNCW Physics Family. Be sure to send your updated address!

Send your update to:

brownf@uncw.edu

or complete form on web at:

www.uncwil.edu/alumni

Student Update

On April 22, 2004, four undergraduate students were inducted into the UNCW chapter of Sigma Pi Sigma, the national physics honor society. They are **Camilo Andres Alvarez**, **Steven Patrick Cash**, **Galen Joseph Gresalfi**, and **Christopher Adams Tate**. Refreshments (pizza and soda) were served during a social hour following the ceremony.

Jerry Jones was named the Walter Schmid Award winner at the Spring 2004 Commencement ceremonies. The Schmid Award is given annually to the graduating senior who shows the greatest potential for contributing to the field of theoretical or applied physics. Jerry also was the recipient of the Bernard Wilson Scholarship for the 2003-2004 academic year, and the Outstanding Minority Student Award presented by the College of Arts and Sciences.

Camilo Alvarez is the 2004 recipient of the J. Marshall Crews Scholarship in Science. This is a UNCW merit-based award for rising juniors or seniors in a science field, and provides for the full cost of tuition, fees, books, and supplies. Camilo is the first physics Crews Scholar since the award was established in 2001. Camilo also is the recipient of the Hildelisa

Hernandez Departmental Award in Physics and a UNCW Bookstore Scholarship. The Hernandez Award, named for retired Professor Emeritus Hildelisa Hernandez, recognizes outstanding academic achievement of a member of the junior class who is seeking the B.S. degree in physics.

Rogan Cronin, **Galen Gresalfi**, and **James Sheffield** were tapped by faculty member Professor Liping Gan to assist at Jefferson Lab during the summer of 2004 in developing a low energy recoil detector for experiments designed to test predictions of QCD (Quantum Chromodynamics). This is the second such appointment for Galen. Galen has spoken about his research experience at three professional gatherings: the Triangle Undergraduate Research Symposium, Duke University (November, 2003); the 70th Annual Southeastern Section Meeting of the American Physical Society (SESAPS), Wrightsville Beach, NC (November, 2003); and the 2004 CAA Undergraduate Research Conference, University of Delaware (February, 2004). Galen also is the recipient of one of two UNCW Bookstore Scholarships for the 2003-2004 academic year.

Alumni Notes

Elaine Braman (B.S. Physics, 2004) will enter the Masters Degree Program at Southern Illinois University, Edwardsville where she will study photonics. Elaine will begin in the Spring 2005 term and has been awarded a Teaching Assistantship.

Laura Guy (B.S. Physics, 2003) has been accepted into the Physics Graduate Program at NCSU for the Fall 2004 semester. Following her December graduation from UNCW, Laura spent the Spring 2004 term at George Mason University where she was a graduate student majoring in physics.

Jeremy Pesicek (B.A. Physics, 2003) has entered the University of Wisconsin – Madison in Fall 2004 to study geophysics under the tutelage of Professor Cliff Thurber.

Douglas King (B.S. Physics, 2002), completed his M.S. degree in physics from UNC Chapel Hill in August 2004. The title of his thesis was “*Models of feature selectivity in the mammalian visual cortex*”. Currently Doug is seeking to relocate, and is applying to graduate schools outside the area where he hopes to resume studies

“Dr. Black’s Fearless Honors Lab Students Laugh In The Face of Death As They Prepare to Launch ‘Osama the Scarily Large Rocket’”.



Left to right: Nate Kirk, Catherine Higgenbotham, Matt Reece, Brandon Kantmann, Tara Prieve, “Osama the Rocket” (on launch pad), and Rick McMahon.



Colloquium RoundUp

The highlight of this past year's colloquium series was the April 22 public lecture by guest speaker Dr. Sten Odenwald, an astronomer with NASA's Goddard Space Flight Center in Greenbelt, MD. The lecture was timed to coincide with the 2004 Sigma Pi Sigma induction ceremony that immediately followed the talk. In addition to being a highly respected astronomer, Dr. Odenwald is a well-known educator and creator of the award winning website, the Astronomy Café (www.astronomycafe.net). His visit was sponsored by the Harlow Shapley Visiting Lectureship in Astronomy, a program of the American Astronomical Society. This marks the third time in the last four years we have benefited from their sponsorship.

Spring 2004:

Scott Watson, "*Inflation from String Theory*"
Brown University (UNCW Spring 2000 Graduate)
January 16

Dr. Eddie Olszewski, "*Toward Unification of the Basic Natural Forces*", Professor, Physics & Physical Oceanography, University of North Carolina-Wilmington
PART I: January 30; PART II: February 6

Richard Kamens, "*Secondary Organic Atmospheric Aerosol Formation: Is It Important?*", Professor, Department of Environmental Sciences and Engineering, UNC-Chapel Hill, February 20

Paul H. Frampton, "*Theoretical Cosmology*"
Professor, Department of Physics and Astronomy, University of North Carolina, Chapel Hill, February 27

Casey Miller, "*Multiscale Models of Multiphase Porous Medium Systems*", Professor and Chair, Department of Environmental Sciences and Engineering, UNC-Chapel Hill, March 5

Joshua Kessler, "*The Discovery of the Exotic Penta-Quark Particle*" His presentation was followed by **Galen Gresalfi**, "The Student Experience at Jefferson National Laboratory", UNCW students, March 19.

Jian-ping Chen, "*Spinning the Nucleon into Sharper Focus*", Staff Scientist, Jefferson Lab, Newport News, VA, March 26

Sten F. Odenwald, "*New Discoveries in 21st Century*" Astronomy Astrophysicist, Applied Research Corp., Landover, MD., April 22 and "*The Past as Prologue - What to expect from the next sunspot cycle*", April 23

Fall 2004:

Gregg Snedden, "*Physical Oceanography of the Mississippi River Delta*" Professor, Louisiana State University, September 24

Dr. Richard Creswick, "*Time's Arrow and the Second Law of Thermodynamics*", Professor, Department of Physics and Astronomy, University of South Carolina, October 22

Dr. Sergei Matinyan, "*Quantum Chaos and Riemann Hypothesis*", Professor, Yerevan Physics Institute, Armenia, Associated Universitie, October 29

Dr. Paul Tiesenga, "*Neurophysics of attention, or $1+4$ equals 3*", Professor, Department of Physics and Astronomy, University of North Carolina at Chapel Hill, November 5

Dr. Daniel Reichart "*Gamma-Ray Bursts as Probes of the Early Universe*", Professor, Department of Physics and Astronomy University of North Carolina at Chapel Hill November 12

Mr. Galen Gresalfi, "*Dark Matter*" and **Mr. Chris Long**, "*The Higgs Boson*", UNCW students, November 19

All Colloquia are free and open to the public. You are cordially invited to attend. The very latest Colloquium information is always available from the Department web page at <http://www.uncw.edu/phy>.

instances of disentanglement. These disentangled composite states are the steady states that would evolve in a lossless quantum cavity. For appropriate coherent superposition, the field radiation evolves into a pure state that is a macroscopic quantum superposition of two super-Poissonian photonic states, a Schrödinger-cat state.

These newly introduced odd states have both classical and quantum features since they can possess both super-Poissonian and sub-Poissonian statistics, albeit the state is not a squeezed state. Accordingly, the steady state is a linear superposition of a squeezed, super-Poissonian state plus a state that can possess either super-Poissonian or sub-Poissonian statistics, but is not a squeezed state. The nature of the initial state of the electromagnetic field in the cavity determines the properties of the overall photonic steady state. One can produce steady states composed of a continuous admixture of a squeezed vacuum and an odd photonic state by the proper initial admixture in the cavity of even- and odd-photon-number states. We show that the squeezed vacuum and the odd states are analogous to the zero-photon (the vacuum) and the one-photon states, respectively. This correspondence suggests the use of the squeezed vacuum and the odd atom-field states as basic constituents for qubits for quantum computation and quantum information.

The fundamental principle of superposition asserts that the arbitrary linear combination of two states of a quantum mechanical system is itself a possible state of the system. Note that a classical bit is either in one state or in the other. However, in a qubit the system is in a linear superposition of two quantum states, which does not specify in which of the two states the system is in. It is only upon measuring the state of the quantum system that the measurement process forces the system into either one of the two states. Quantum mechanics gives the probabilities of such outcomes for a particular superposition of the two states.

The linear superposition principle in quantum mechanics is bewildering enough. If a photon travels through a beam splitter, then the outgoing photon actually travels on both paths simultaneously and is forced into one path or the other only upon measurements of its whereabouts. This effect is known as particle interference. However, the most striking feature of the new

mechanics is quantum entanglement, with particle interference pales in comparison.

If one considers a composite system, say the quantum systems A and B, then entangled states of the composite system exist such that if one makes a measurement on system A, then system B is forced into a particular state, which is determined by the original entangled state. The fact that the quantum systems A and B may still be correlated when a large distance apart gave rise to the strange properties first pointed out by Einstein, Podolsky and Rosen. Einstein referred to this quantum behavior as “spooky action at a distance.”

The no-cloning theorem for pure states, discovered in the early 1980s, is one of the earliest results of quantum computation and quantum information. The no-cloning theorem states that it is impossible to make a copy of an unknown, pure quantum state. The theorem places a limit on the ability to manipulate quantum information. It follows from the no-cloning theorem that no copying machine can make perfect copies of all incoming states, if they are not all orthogonal to each other. The no-cloning theorem places a limit on how well we can know an arbitrary state. It is interesting that the no-cloning theorem is instrumental in preventing superluminal communication, in complete agreement with Einstein’s theory of special relativity. The latter is rather curious since the quantum mechanical basis of the no-cloning theorem is not obviously relativistic. However, it is the failure of local realism owing to the nonlocal nature of quantum entanglement that closely have suggested the possibility of superluminal communication being in the first place that, however, is forbidden by the no-cloning theorem. The difference in quantum copying is that the original state is destroyed in the process. However, the whole idea of quantum cloning is to produce at the output of the cloning machine two identical pure states, which are unitarily connected with the input pure state. We recently proposed and realized this less restrictive condition for cloning in the exact cloning of nonorthogonal coherent states in a two-mode cavity via Raman scattering². Prior to this result, in a Gaussian quantum-cloning [see QUANTUM, page 8](#)