The OSA Quantum Computing and Communication Technical Group Welcomes You!

QUANTUM MECHANICS WITH CLASSICAL LIGHT
3 October 2019 • 10:00 EDT
Technical Group Leadership 2019

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Technical Group at a Glance

• Focus
  • Theoretical and experimental aspects of quantum computing
  • Quantum communication systems - Cryptography
  • Generation, detection and applications of non-classical light
  • Quantum measurement and quantum control

• Mission
  • To maximize the exchange of information and the creation of networking opportunities for our community
  • Webinars, technical events (workshops, tutorials, poster sessions), outreach activities
  • Interested in presenting your research? Have ideas for TG events? Contact us at TGactivities@osa.org.

• Find us here
  • Website: www.osa.org/OC
  • Facebook: https://www.facebook.com/groups/OSAQuantumCC/
Today’s Webinar

Quantum Mechanics with Classical Light?

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Speaker’s Short Bio:

Andrew Forbes is a distinguished Professor in the Wits School of Physics and Head of the Structured Light Laboratory. He serves on committees of several international conferences such as, OSA and SPIE. Dr. Forbes is on the editorial boards of Optics Express and J. Optics. He is the founding member for the Photonics Initiative of South Africa, a Fellow of both SPIE and the OSA, and an elected member of the Academy of Science of South Africa. Dr. Forbes won a 2015 national award for his contribution to photonics in Africa.
Quantum mechanics with classical light

Andrew Forbes
Structured Light Laboratory
U. Witwatersrand: “Vits”  
4 Nobel Laureates  
~100 years old
Structured Light
By your method of choice
Any mode can be created

Using complex amplitude modulation on an SLM
Laser light

Structured light at the source for high-brightness lasers
Classical light

For high-bandwidth optical communications and metrology
Quantum light

High-dimensional entanglement for communication and imaging
Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. Einstein, B. Podolsky and N. Rosen, Institute for Advanced Study, Princeton, New Jersey
(Received March 25, 1935)

Quantum mechanics: measurements on one particle dictate the state of the other particle.
Spontaneous parametric down conversion

Nonlinear crystal

Quantum collapse
\[ |\Psi\rangle = \frac{1}{\sqrt{2}} (|H\rangle_A |V\rangle_B - \frac{1}{\sqrt{2}} |V\rangle_A |H\rangle_B) \]

Reality #1

Reality #2
We are interested in entangled photonic states

System $S$

Particle A

State: $|0\rangle$ $|1\rangle$

Particle B

State: $|0\rangle$ $|1\rangle$

$|\Psi\rangle_S = |\text{state}\rangle_A \otimes |\text{state}\rangle_B$

NO ENTANGLEMENT  SEPARABLE STATE
We are interested in entangled photonic states

\[ |\Psi\rangle_S = |\text{state}\rangle_A \otimes |\text{state}\rangle_B \]

ENTANGLEMENT NON-SEPARABLE STATE

\[ |\Psi\rangle_S = |0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B \]
We will consider OAM as our “pattern”
We will consider OAM as our “pattern”
... with polarisation superpositions to create vector vortex beams
Vector vortex states of light can be mapped on a higher-order Poincaré sphere

\[ \alpha |L\rangle + \beta |R\rangle \]

\[ \frac{1}{\sqrt{2}} (|L\rangle + i|R\rangle) \]

\[ \frac{1}{\sqrt{2}} (|L\rangle - i|R\rangle) \]

\[ \frac{1}{\sqrt{2}} (|\ell\rangle + | - \ell\rangle) \]

\[ \frac{1}{\sqrt{2}} (|\ell\rangle - i| - \ell\rangle) \]

\[ \frac{1}{\sqrt{2}} (|\ell\rangle + i| - \ell\rangle) \]

\[ \frac{1}{\sqrt{2}} (|\ell\rangle - | - \ell\rangle) \]


Vector vortex states of light can be mapped on a higher-order Poincaré sphere

\[ |U\rangle = \alpha | - \ell \rangle |L\rangle + \beta |\ell \rangle |R\rangle \]
What is your favourite method to create such modes?


Ritsch-Marte: NJP 9, 78 (2007)

Marrucci: PRL 10, 327 (2006)

Karimi: LSA 3, e167 (2014)


Brasselet: PRL 103, 103903 (2009)

Capasso: Science 358, 896 (2017)

Zhan: OL 40, 1691 (2015)

Litchinitser: Science 353, 464 (2016)

They have the interesting property of a spatially variant polarisation

Scalar beams

Vector beams
So vector (vortex) beams have inhomogeneous polarisation distributions.
Vector vortex modes have inhomogeneous polarisation distributions ... non-separable states

Vector mode

Vector vortex beam

\[ |\Psi\rangle = |\ell\rangle_1|R\rangle_2 + |-\ell\rangle_1|L\rangle_2 \]

Equivalent?

Quantum entangled state

\[ |\Psi\rangle = |\ell\rangle_1|-\ell\rangle_2 + |-\ell\rangle_1|\ell\rangle_2 \]
Isn’t this reminds us of quantum entanglement?

Entanglement:

\[ |\psi\rangle_{AB} = |\ell\rangle_A |\ell\rangle_B + -|\ell\rangle_A |\ell\rangle_B \]

Vector beams:

\[ |\psi\rangle = |\ell\rangle R\rangle + -|\ell\rangle L\rangle \]
A measurement on one degree of freedom affects the outcome of the other.
Classical Entanglement

Non-separable states of light
Can we use quantum tools to describe vector beams?
Quantum State Tomography: performing various projections to unravel an unknown state

Quantum State Tomography: performing various projections to unravel an unknown state
The experiment to implement this is very simple
The measurement outcome of a QST on classical light

\[ |\Psi\rangle = \frac{1}{\sqrt{2}} \{ |\ell\rangle |R\rangle + | -\ell\rangle |L\rangle \} \]

\[ |\Psi\rangle = | -\ell\rangle |L\rangle \]
And then show that the classical state looks entangled!

$$\rho = \ket{\Psi}\bra{\Psi}$$

$$|\Psi\rangle = \ket{\ell} R$$

$$|\Psi\rangle = \frac{1}{\sqrt{2}} \left( \ket{\ell} R + |-\ell\rangle L \right)$$

Purely scalar

Purely vector

Degree of non-separability
And it works: here is quantum and classical data side by side.
Vector beams violate a Bell inequality

\[ |\Psi\rangle = -\ell |L\rangle \]

\[ |\Psi\rangle = \frac{1}{\sqrt{2}} \left( \ell |R\rangle + -\ell |L\rangle \right) \]
Quantum computing algorithms
With classical light?
We can use classical light to mimic many quantum processes: the Grover algorithm.
We can use classical light to mimic many quantum processes: the Grover algorithm.

\[ U\psi \rvert \psi \rangle \]

\[ \pi \text{-phase shift} \]

\[ \pi/2 \text{-phase shift} \]

Input beam

M1

L1

\[ \psi \rvert x,s \rangle \]

L2

M2

Output beam

Blurring the classical-quantum divide with vector states of light.

**QUANTUM**

Perturbed eigenstates \(\{|\ell\rangle_A, |\ell\rangle_A\}\)

**CLASSICAL**

Perturbed eigenstates \(\{|\ell\rangle_A, |\ell\rangle_A\}\)
Nature can’t distinguish between the decay of vector vortex beams and the decay of OAM quantum entangled states.
We can convert noise into loss and recover the fidelity of the quantum state.

Nature Physics 13, 397 (2017)
QWs with classical light

We only need superpositions
Vector beams

Scalar beams

Quantum (wave) mechanics

Classical wave mechanics

Classical particle mechanics

Konrad & Forbes, *Quantum Mechanics and Classical Light*
Contemporary Physics 60, 1 (2019)

Forbes, Aiello & Ndagano, *Classical Entanglement*
Progress in Optics 64, 99 (2019)

Toninelli et. al., *Concepts in quantum state tomography and classical implementation with intense light: a tutorial*
Thank You

www.structuredlight.org