Photon Statistics

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Motivation

Measuring the diameter of a star: Michelson Stellar Interferometer

\[ \lambda \approx d_{\text{coh}} \alpha \]

Problem:
phase fluctuations

Interference
of fields

Same beam
Motivation

Hanbury Brown and Twiss Interferometer

Intensity

Photon statistics

H. Paul, Photonen, Teubner 1995
• First glance on coherence: HBT experiment 1956
• Characterization of Light: 1965
• Bunching: 1966
• Antibunching: 1977
Coherence: HBT experiment

Lab experiment:

**Hanbury-Brown and Twiss Experiment**

- Hg light
- PMT 1
- Amplifier
- Correlator
- Integrator

\[
d = 0
\]

Same spatial mode

(movable)
Results:

• Positive normed correlation in all cases
• This correlation disappeared for \( d \geq d_{coh} \)
Conclusions:

• Photoelectric emission preserves correlation
• Photons in coherent thermal light correlated more than random
• Setup for measurement of photon statistics
• First glance on coherence: HBT experiment 1956
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Characterization of Light

Different light source
→ different photon statistics

\[ T \leq t_{\text{coh}} \]
Characterization of Light

Generation of quasi-thermal light:

Variable speed dc motor → Laser

The Ground Glass Disk

Focused laser beam

disk→ lens

Focused wavefronts

disk surface (smooth)

Spherical wavefronts

disk surface (sandblasted)

t$_{coh}$ adjustable

ground glass disk

PMT

carboard box

mxp.physics.umn.edu
Characterization of Light

G: Bose
L: Poisson

complete statistical information of the radiation field

F.T. Arecchi, PRL 15, 912 (1965)
Characterization of Light

Switching on of a Laser:

F.T. Arecchi, PRL 19, 1168 (1967)
• First glance on coherence: HBT experiment 1956
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Bunching

HBT experiment

photons of a thermal light do not arrive completely at random

Distribution of time intervals between successive counts

spectral profile \( t_{\text{coh}} \Delta \nu \approx 1 \)
Bunching

Mercury lamp:

Tungsten lamp:

B.L. Morgan and L. Mandel, PRL 16, 1012 (1966)
Bunching

Auto-correlation function

spectral profile of thermal light
Why is there bunching in thermal light?

- Wave character of photons
- Radiation field is smooth function
Outline

• First glance on coherence: HBT experiment 1956
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Antibunching

Non-classical light: single photon source

|2> |  |  |  |
|---|---|---|---|
|1> |  |  |  |

Excitation  Emission  Excitation  Emission

Time
Antibunching

Experimental setup:
Antibunching

Less coincidences for short $\tau$

H.J. Kimble, M. Dagenais and L. Mandel, PRL 39, 691 (1977)
Antibunching

H.J. Kimble, M. Dagenais and L. Mandel, PRL 39, 691 (1977)
Antibunching

H. Paul, Reviews of Modern Physics, Volume 54, Issue 4, October 1982, pp.1061-1102
Antibunching

\[ I(t) = I_0 + \delta I(t) \quad <I(t)> = <I_0> + <\delta I(t)> \]

\[ <I(t) I(t+\tau)> = <I_0 I_0> + <\delta I(t) \delta I(t+ \tau)> \]

\[ <\delta I(t) \delta I(t+ \tau)> = 0 \quad \text{for } \tau \gg 0 \]

\[ <\delta I(t) \delta I(t+ \tau)> = <\delta I(t)>^2 \quad \text{for } \tau \rightarrow 0 \]

\[ <\delta I(t)>^2 > 0 \]
Antibunching is direct evidence for the quantisation of the electromagnetical field. It also shows that the atom is undergoing a quantum jump.
# Summary

| Light source:   | thermal | Laser | Single-photon |
|----------------|---------|-------|---------------|
| Statistics:    | Bose    | Poisson | Sub-Poisson  |
| Correlation:   | Bunching| flat   | Antibunching  |

H. Paul, Photonen, Teubner 1995

harvard.edu
• H. Paul, Photonen, Teubner 1995
• R. Hanbury Brown and R.Q. Twiss, Nature 177, 27 (1956)
• F.T. Arecchi, PRL 15, 912 (1965)
• B.L. Morgan and L. Mandel, PRL 16, 1012 (1966)
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