L8: $g^{(2)}$ for light and atoms

$g^{(2)}(0)$ normalized probability to detect two photons (particles) simultaneously

So far: light

thermal/chaotic/classical light $g^{(2)} = 2$ bunching

Laser / coherent light $g^{(2)} = 1$

single photon $g^{(2)} = 0$

Is $g^{(2)} = 2$: Is this a classical or a quantum effect?

4 different views

① Random intensity fluctuations, Gaussian distribution

$$p(I) = \frac{1}{\langle I \rangle} \exp\left(-I / \langle I \rangle\right)$$

$$\langle I^n \rangle = n! \, \langle I \rangle^n \qquad n=2: \langle I^2 \rangle = 2 \langle I \rangle^2$$

$$g^{(2)} = \frac{\langle I^2 \rangle}{\langle I \rangle^2} = 2$$

First photon is more likely to be detected when intensity fluctuations gives high intensity.

(2) Wave interference

One mode (laser, BEC)

Single wave $e^{i(\omega t - kz)}$

all correlation functions factorize

$$\Rightarrow \langle I^n \rangle = \langle I \rangle^n$$

$$\Rightarrow g^{(n)} = 1 \quad \text{for all } n$$

two (or more) modes

"simple" model

two modes, both of int. 1 $\Rightarrow \langle I \rangle = 2$

interference $\Rightarrow$ Intensity varies between 0 and 4

I^2 " " 0 and 16

$$\Rightarrow \langle I^2 \rangle = 8 = 2 \cdot \langle I \rangle^2$$

$$\Rightarrow g^{(2)} = 2$$

demonstrates that $g^{(2)} = 2$ has its true origin in wave interference

Exp. intensity distribution in (1) is the result of interference

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(3) Classical vs quantum statistics

n particles, N quantum states $n \ll N$

classical:

Prob. to find 1 particle $P_1 = \frac{n}{N}$

2 particles $P_2 = P_1^2$

indistinguishability of particles:

P_1 reduced by $n!$

P_2 $\frac{n!}{2}$

bosons: $P_2^{bosons} = 2\left(P_1^{bosons}\right)^2$

Applications to collisions in a Bose gas:

2-body collisions $\Gamma_2 \propto g^{(2)}$

3- " " $\Gamma_3 \propto g^{(3)}$

at the same density

$$\Gamma_2^{thermal} / \Gamma_2^{BEC} = 2 = 2!$$

$$\Gamma_3^{thermal} / \Gamma_3^{BEC} = 6 = 3!$$

Refs: 3 body Burt et al., PRL 79, 337 (1997)

2 body WK, Miesner PRA 56, 3291 (1997)

4 QM explanation

detection (collision) of two particles in two modes a_1, a_2 has exchange term $a_2^\dagger a_1$

→ Factor of 2 bosons $g^{(2)} = 2$

→ Factor of 0 fermions $g^{(2)} = 0$

Single mode: $a_1^\dagger a_1$ has no exchange term (law, etc) ⇒ $g^{(2)} = 1$

Measurements of $g^{(2)}$

Common denominator

Detection of particles in

- one quantum state
- one mode
- one coherence volume
- one phase space cell

p probability to find one particle

p^2	classical	to find two particles
$2p^2$	bosons	
0	fermions	

<u>Ex:</u> Atom cloud

$(\lambda_{dB})^3$ Coherence volume $\hat{=}$ one phase space cell h^3

$\downarrow$ drop and expand

— — transverse coll

$\Rightarrow$ $\Leftarrow$ detection law

$\Rightarrow$ temporal resolution

Selects one phase-space cell