Optical Frequency Doubling

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What is a Bose-Einstein Condensate?

A very cold ($\sim$ 100nK), and very dense ($\sim 10^{13}$ cm^{-1}) cloud of (in this case) 87 Rb created in the lab.

Can be used to simulate solid-state systems when placed in a periodic potential called an optical lattice, which is formed by the interference of counterpropogating laser beams.

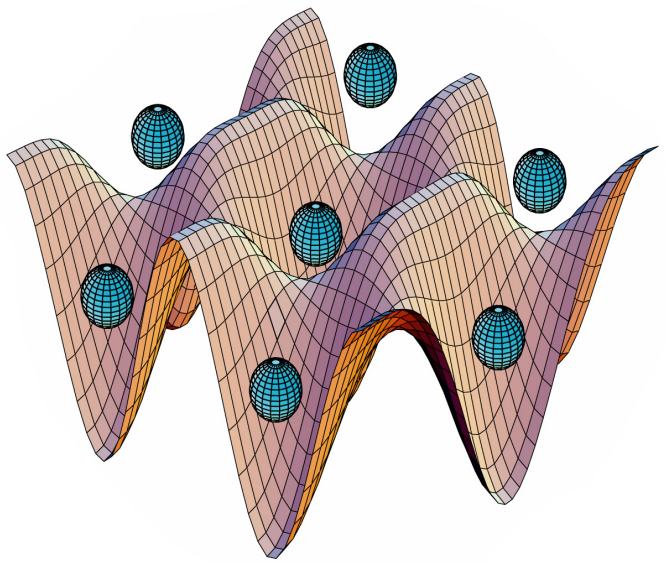


Figure:
http://www.physics.umd.edu/rgroups/amo/rolstonwebsite/bec.htm

Motivation for Frequency Doubling

- A recent paper suggests a method for faster adiabatic loading of the condensate into an optical lattice using the non-linear interaction of laser light and its frequency-doubled counterpart.
- This non-linear interaction is very susceptible to phase drifting, so using two lasers is out of the question.
- Solution is to beam-split the laser and double one beam's frequency in real time so that the two waves stay phase despite phase drift.

High-Fidelity Rapid Ground-State Loading of an Ultracold Gas into an Optical Lattice- S. Masuda, K. Nakamura, A. del Campo, Phys. Rev. Lett. 113, 063003 (2014)

Theory of Second Harmonic Generation: Photon Scale

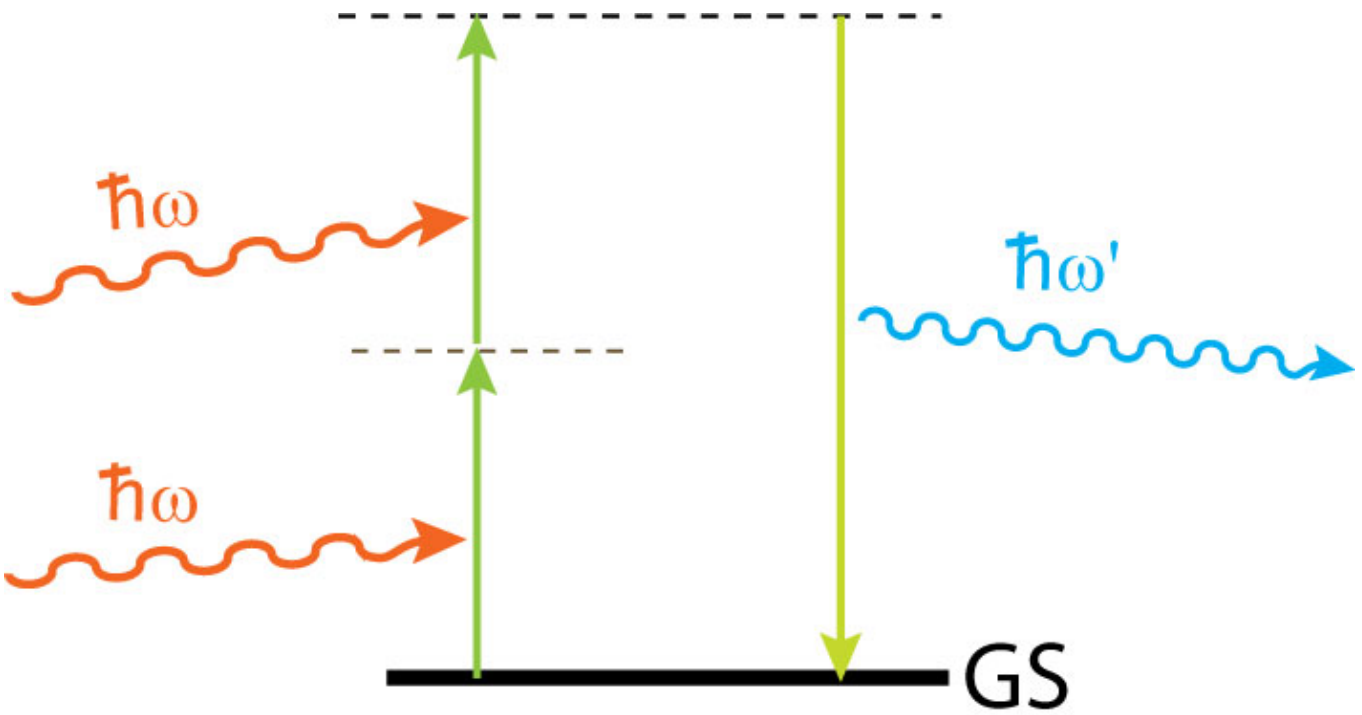


Figure: `http://www.phys.vt.edu/~hansr/Projects/SHG.jpg`

Theory of SHG: Overdriven Harmonic Oscillator Model

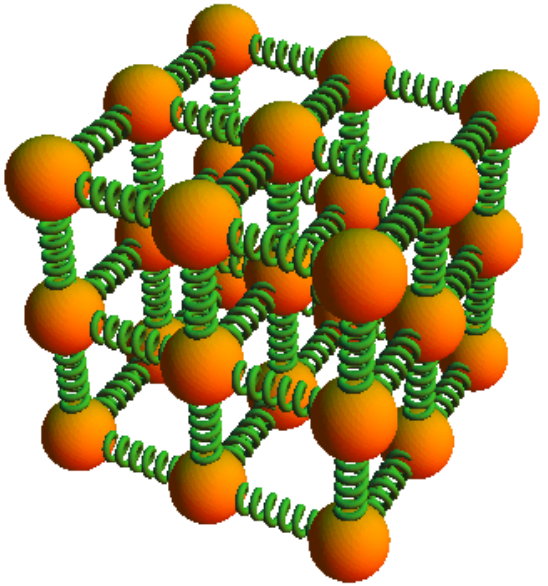


Figure: `http://www.phys.vt.edu/~hansr/Projects/SHG.jpg`

- Approximate atoms as electrons on springs. When springs are overdriven by a driving force of frequency ω their motion contains a component at frequency 2ω
- Requires high-amplitude electromagnetic fields, so SHG was not discovered until invention of the laser in 1960.

SHG Theory Continued

- Assume high-amplitude incident electric field given by $E(t) = \frac{1}{2}(E_0 e^{-i\omega t} + E_0^* e^{i\omega t})$ (a plane wave).
- In Newtonian analysis of overdriven oscillator model, $x(t)$ will have a component proportional to E^2.
- Polarization density (dipole moment/unit volume) may be written as $P^{(1)} = \epsilon_0 \chi^{(1)} E$ or $P = Nex(t)$ where N is the number of atoms per unit volume.
- Large E: Expand polarization density as Taylor series about $E = 0$
- $P = a_1 E + \frac{1}{2} a_2 E^2 + \ldots$ where a_n is the nth derivative of P w.r.t. E.
- Since $x(t)$ has a nonzero E^2 term and $P = Nex(t) = a_1 E + \frac{1}{2} a_2 E^2 + \ldots$, then the E^2 term in the Taylor series is also nonzero.

SHG Theory Continued

$$\begin{aligned} P^{(2)} =& \chi^{(2)} E^2 \\ =& \chi^{(2)} \left[\frac{1}{2} (E_0 e^{-i\omega t} + E_0^* e^{i\omega t}) \right]^2 \\ =& \chi^{(2)} \frac{1}{4} \left[E_0^2 e^{-i2\omega t} + (E_0^*)^2 e^{i2\omega t} + 2E_0 E_0^* \right]. \end{aligned}$$

$\rightarrow$ Polarization density has component oscillating at frequency 2ω.
Maxwell's Equations:

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$$

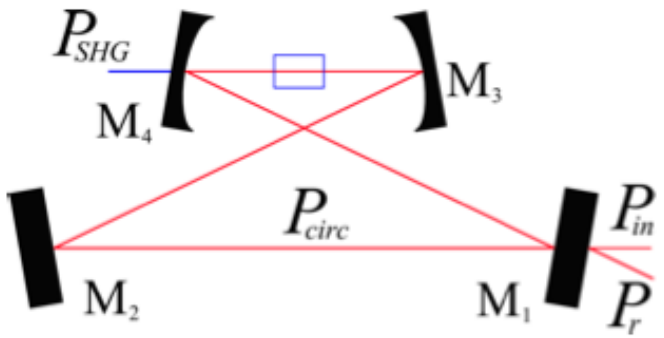
and

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$$

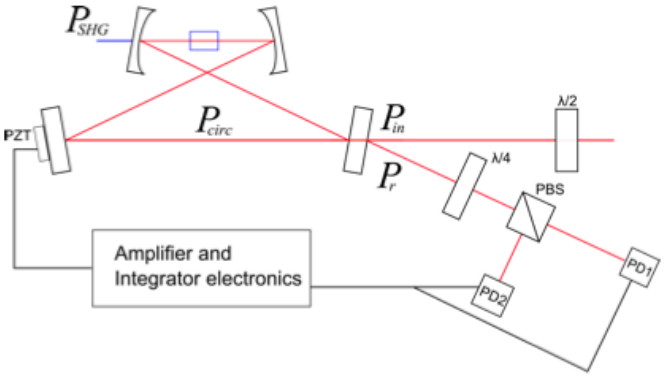
$$\vec{J} = \sigma \vec{E}$$

Method for Frequency Doubling

- Some nonlinear crystals double laser light. We have obtained a barium borate crystal (BBO) to frequency double $\sim$ 800nm laser light.
- Output intensity is $< 1\%$ of input intensity
- Solution is resonant bowtie mirror cavity to grow amplitude of fundamental wave.



(a) Bowtie mirror configuration



(b) Using a Piezo-electric transducer (PZT) to maximize output intensity