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## Synchronization of interacting quantum dipoles

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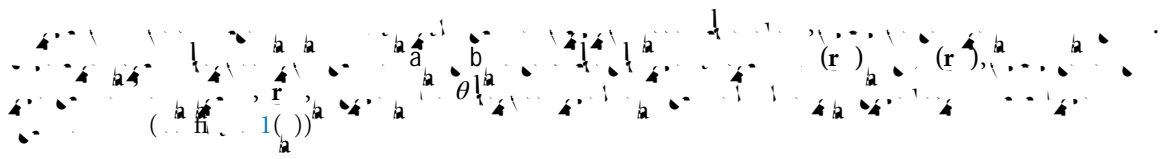
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## 2. Dipole-dipole interaction and master equation



$$- \frac{1}{4\pi\epsilon_0} \frac{1}{r^3} \left( \frac{3}{r} \frac{p_a \cdot r}{r} - p_a \right) \cdot p_b$$

$$- \frac{1}{4\pi\epsilon_0} \frac{1}{r^3} \left( \frac{3}{r} \frac{p_b \cdot r}{r} - p_b \right) \cdot p_a$$

### 3. Mean-field treatment and connection to the KM

$$\hat{\rho} = \frac{1}{2^N} \sum_{\sigma, \sigma'} \rho^{\sigma, \sigma'} \sigma \sigma' \quad (2 \times 2)$$
$$\rho = \frac{1}{2} \{ \sigma, \sigma' \}$$

$$\frac{d}{d} (\ ) \quad \text{---} \prime (\mathbf{r}) \cos \quad \prime (\mathbf{r}) \sin \quad , \quad (7)$$

#### 4. Quantum synchronization for the collective system

$$N \langle \mathbf{r} \rangle_{\text{eff}} = \sum_{\mathbf{r}} \mathbf{r} \rho(\mathbf{r}) \quad \delta = 0 \quad (1) \quad \rho(\mathbf{r}) = 0$$





$$\begin{aligned}
& \lim_{\delta \rightarrow 0} (\hat{\sigma}^+(x+\delta) + \hat{\sigma}^+(x-\delta)) (\hat{\sigma}^-(x+\delta) + \hat{\sigma}^-(x-\delta)) \\
& \quad = 2 \hat{\sigma}^+(x) \hat{\sigma}^-(x) \\
& \quad = 2 A \cos(\gamma x) \exp(-\gamma |x|) \\
& \quad = 0.
\end{aligned}$$

$x \in [-\pi/2, \pi/2]$ ,  $N = 100$ ,  $a = 101$

$$\nabla \cdot \mathbf{v}(\mathbf{r}) = 0,$$

The image shows a page of musical notation for a string quartet, consisting of four staves. The notation includes various musical symbols such as notes, rests, and dynamic markings. The dynamics include *f*, *ff*, and *φ*. There are also performance instructions like *rit.* and *rit. 6*. The notation is dense and spans across the four staves, with some markings appearing in specific measures. The overall appearance is that of a professional musical score.

## Appendix A. Incoherent pumping

$$\begin{aligned} \dot{\rho}_{fi} &= -\Gamma_{fi} \rho_{fi} + \Gamma_{if} \rho_{if} + \Gamma_{fj} \rho_{fj} - \Gamma_{jf} \rho_{jf} + \Gamma_{f3} \rho_{f3} - \Gamma_{3f} \rho_{3f} \\ &= -\Gamma_{fi} \rho_{fi} + \Gamma_{if} \rho_{if} + \Gamma_{fj} \rho_{fj} - \Gamma_{jf} \rho_{jf} + \Gamma_{f3} \rho_{f3} - \Gamma_{3f} \rho_{3f} \\ &= -\Gamma_{fi} \rho_{fi} + \Gamma_{if} \rho_{if} + \Gamma_{fj} \rho_{fj} - \Gamma_{jf} \rho_{jf} + \Gamma_{f3} \rho_{f3} - \Gamma_{3f} \rho_{3f} \end{aligned}$$

3 =  $\varphi$

Handwritten musical notation on a staff. The notation includes a treble clef, a key signature of one flat (B-flat), and a time signature of 3/4. The melody consists of several measures of music with notes and rests. A dynamic marking 'f' (forte) is present at the beginning. The notation is somewhat faint and appears to be a sketch or a handwritten score.

$$e^i = \frac{1}{N} \sum_{\mathbf{r}} e^{i\varphi_{\mathbf{r}}} \quad \text{eff} = \dots \quad (\mathbf{r}) / (N - 1)$$

$$\text{eff} = \dots \quad (\mathbf{r}) / (N - 1).$$

$$\bar{F}(\hat{\cdot}) = (F(J) \ F(J) \ F(J))$$

01 Phys. Rev. Lett. [111](#) 10

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