

Title: Manybody Physics meets Quantum Engineering

Date: Jun 26, 2007 09:00 AM

URL: <http://pirsa.org/07060071>

Abstract:

1. Oscillator baths

(a) justification (or not)

(b) application

2. Topological quantum computing  
(heretical thoughts)

3. Hybrid optical-solid state qubits

maths  
one (or not)

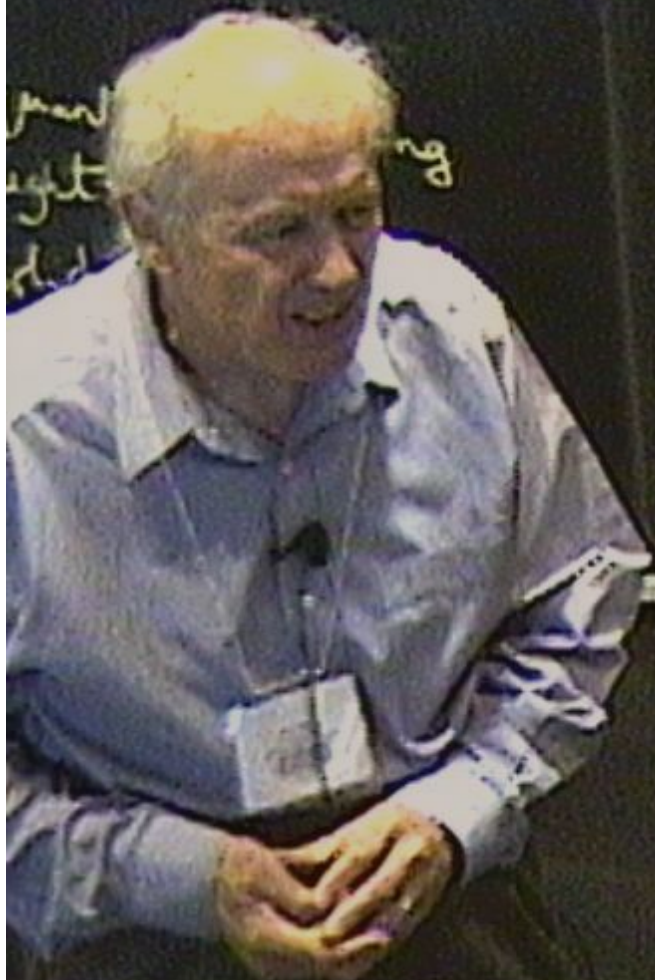
$\mathbb{H}$

$\mathbb{Q}$

mention computer  
rights)  
did state quib

maths  
on (or not)  
m  
part  
right  
died

$$[\Phi, Q] = i\hbar$$



$$[\Phi, Q] = i\hbar$$

1)  $T = 0$

2)  $T = \text{TRI}$

3)

puting

bits

$$[\underline{\Phi}, Q] = i\hbar$$

1)  $T = 0$

2)  $TRI$

3) any one DOF of env't  
weakly perturbed

$$H_{\text{can}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{c-s}} = \sum_j f_j(\mathbf{q}) x_j$$

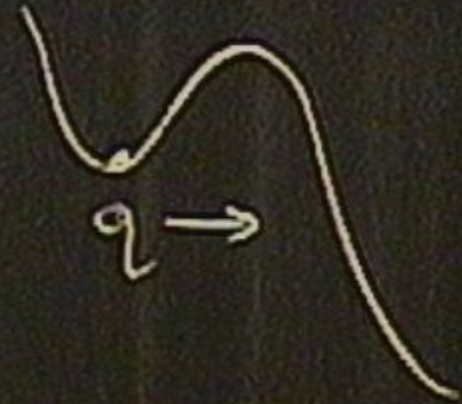
$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{E-S} = \sum_j f_j(q) x_j$$



$$H_{\text{class}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{e-s}} = \sum_j q_j x_j$$



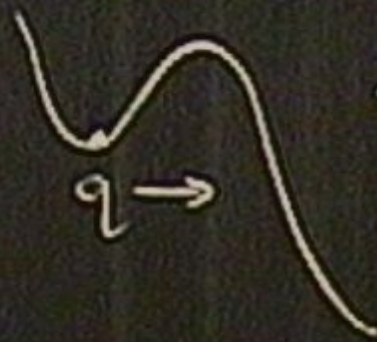
$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{e-s}} = \left( -q \sum_i \frac{1}{r_i} \right) x$$

$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{zi} \hat{\Omega}_i$$

$$H_{\text{osc}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

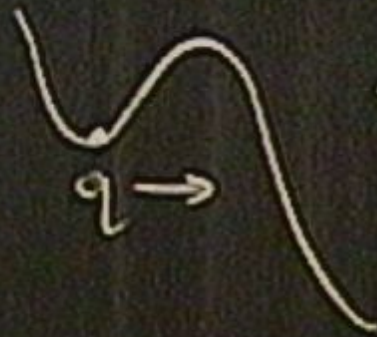
$$H_{\text{c-s}} = \left( \sum_j q_j \dot{x}_j \right)$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \tau_{zi} \hat{\Omega}_i$$

$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

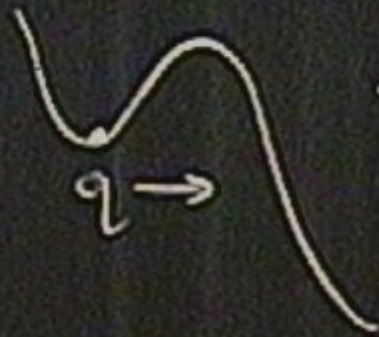
$$H_{\text{e-s}} = \left( \sum_j \frac{q_j}{r_{ij}} \right) x_j$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{xi} \hat{\Omega}_i$$

$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

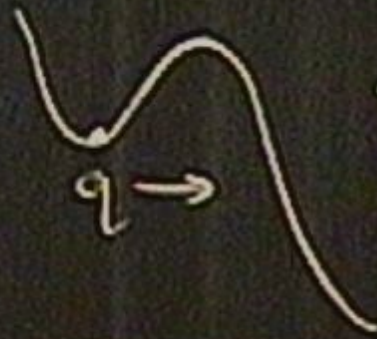
$$H_{\text{c-s}} = \left( -q \sum_j \frac{d}{dt} x_j \right)$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{zi} \hat{\Omega}_i$$

$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{c-s}} = \sum_j q_j x_j$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{zi} \hat{\Omega}_i$$

$$\hat{\Omega}_i = \sum_k q_{ik} x_k$$

$$\hat{H} = \sum_i z_i h_i + \text{SHO's} + \sum_{i,r} g_{i,r} x_r z_i$$



$$\hat{H} = \sum_i z_i h_i + \text{SHO's} \rightarrow \sum_{i,j} g_{ij} x_j z_i$$



$$\hat{H} = \sum_i z_i \beta_i + \text{STIO's} \rightarrow \sum_{i=1}^n g_{i1} x_{i1} z_i$$

$x_{i1}^2$



$$\hat{H} = \sum_i Z_i \mathcal{H}_i + S \hbar \omega' \left( \sum_{i=1}^n g_{i1} x_{i1} Z_i \right)$$

$$\hat{x} = x - \frac{gZ}{\hbar \omega}$$

$$\hat{H} = Z \mathcal{H} + \left( \frac{p^2}{2m} + \frac{1}{2} m \omega^2 \hat{x}^2 \right) - \frac{1}{2} \frac{g^2}{\hbar \omega} Z^2$$

$$\hat{H} = \sum_i Z_i \mathcal{H}_i + \text{SHO's} \rightarrow \sum_{i=1}^n g_{i1} x_{i1} Z_i$$

$$\tilde{x} = x - \frac{gZ}{m\omega}$$

$$\hat{H} = Z\mathcal{H} + \left( \frac{p^2}{2m} + \frac{1}{2} m \omega^2 \tilde{x}^2 \right) - \frac{1}{2} \frac{g^2}{m\omega} Z^2$$

Exact solution of 1DSE for constant

initial condition:

$$\left. \begin{aligned} \psi(x,t) &= \exp - i(E_0 - \frac{1}{2}m\omega^2 x_0^2) t/\hbar \cdot \\ &\exp - \frac{i m \omega^2}{\hbar} (x + x_0) x_0 \sin 2\omega t \cdot \\ &\exp - \frac{i m \omega^2}{4\hbar} x_0^2 \sin 2\omega t \cdot \\ &\psi_0(x + x_0(1 - \cos \omega t)) \end{aligned} \right\}$$

$$x_0(z) \equiv g z / m \omega^2$$

for single-qubit, single-mode case,  $x_0^2$  terms  
constant.

Many-qubit, many-mode case:

$$\prod_k \psi(x_k, t) \quad (\omega \rightarrow \omega_k)$$

$$x_{0k}\{z_i\} \equiv \sum_i (g_{ki} z_i / m \omega_k^2)$$

$x_{0k}^2$  terms nontrivial, but independent of  $m_k$ .  
(for strictly harmonic case)

Exact solution of TDSE for static  
initial condition:

$$\left. \begin{aligned} \psi(x,t) &= \exp - i(E_0 - \frac{1}{2} m \omega^2 x_0^2) t / \hbar \cdot \\ &\exp - \frac{i m \omega^2}{\hbar} (x + x_0) x_0 \sin 2\omega t \cdot \\ &\exp - \frac{i m \omega^2}{4\hbar} x_0^2 \sin 2\omega t \cdot \\ \psi_0(x + x_0(1 - \cos \omega t)) \end{aligned} \right\}$$

$$x_0(z) \equiv gZ / m\omega^2$$

for single-qubit, single-mode case,  $x_0^2$  terms  
constant.

Many-qubit, many-mode case:

$$\prod_k \psi(x_k, t) \quad (\omega \rightarrow \omega_k)$$

$$x_{0k}\{z_i\} \equiv \sum_i (g_{ki} z_i / m\omega_k^2)$$

$x_{0k}^2$  terms nontrivial, but independent of  $m_k$ .  
(for strictly harmonic case)

$$\hat{H} = \sum_i z_i \mathcal{K}_i + \text{Stio's} \rightarrow \sum_{i,j} g_{ij} x_i^2 z_j$$

$$\hat{x} = x - \frac{gZ}{nD}$$

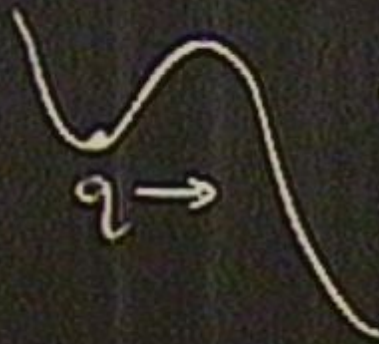
$$\hat{H} = ZK + \left( \frac{1}{2} + \frac{1}{2} n \mathcal{K}^2 \hat{x}^2 \right) - \frac{1}{2} \frac{g^2}{nD^2} Z^2$$

$$\mathcal{K} = \sum_{i,j} \mathcal{K}_{ij} z_i z_j$$

$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{e-s}} = -q \sum_j \frac{1}{r_j} x_j$$

$$|+\rangle + \alpha_+ |+-\rangle + \dots$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{zi} \hat{\Omega}_i$$

$$\hat{\Omega}_i = \sum_k q_{ik} x_k$$

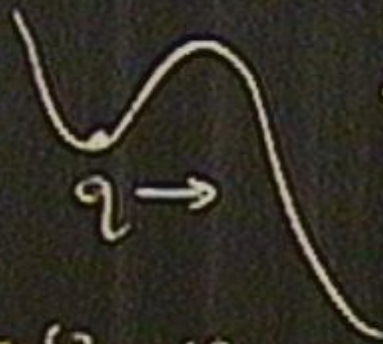
$$H_{\text{em}} = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{\text{e-s}} = -q \sum_j \frac{1}{r_j} x_j$$

$$a_{++} |++\rangle + a_{+-} |+-\rangle$$

$$e^{i\varphi_{++}}$$

$$\varphi_{++} - \varphi_{+-} = \varphi_{+-} - \varphi_{--}$$



$$\mathcal{H} = \sum_i \sigma_{zi} \kappa_i + \sum_i \sigma_{zi} \hat{\Omega}_i$$

$$\hat{\Omega}_i = \sum_k g_{ik} x_k$$



$$H_m = \sum_i \left( \frac{1}{2} m_i \omega_i^2 x_i^2 + p_i^2 / 2m_i \right)$$

$$H_{c-s} = -q \sum_i \frac{1}{r_i} x_i$$

$$a_{i+1} | + \rightarrow + a_{i-1} | + \rightarrow \dots$$

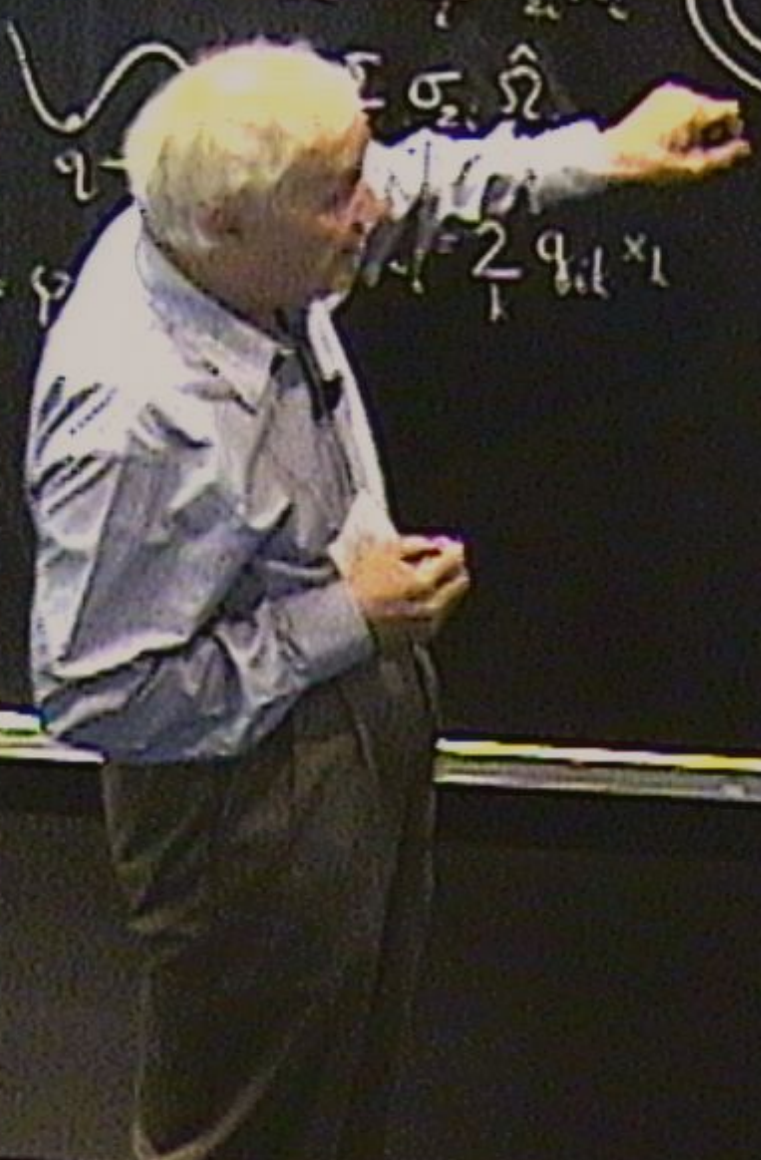
$$e^{i\varphi_{i+1}}$$

$$\varphi_{i+1} - \varphi_i = \varphi$$

$$\mathcal{H} = \sum_i \sigma_{zi} K_i$$

$$\sum_i \sigma_{zi} \hat{\Omega}_i$$

$$= 2 \sum_i q_{bil} x_i$$



Exact solution of TDSE for static  
initial condition:

$$\left. \begin{aligned} \psi(x,t) &= \exp - i(E_0 - \frac{1}{2} m \omega^2 x_0^2) t / \hbar \cdot \\ &\exp - \frac{i m \omega^2}{\hbar} (x + x_0) x_0 \sin 2\omega t \cdot \\ &\exp - \frac{i m \omega^2 x_0^2}{4\hbar} \sin 2\omega t \cdot \\ \psi(x + x_0(1 - \cos \omega t)) \end{aligned} \right\}$$

$$x_0(z) \equiv g z / m \omega^2$$

for single-qubit, single-mode case,  $x_0^2$  terms  
constant.

Many-qubit, many-mode case:

$$\prod_k \psi(x_k, t) \quad (\omega \rightarrow \omega_k)$$

$$x_{0k}\{z_i\} \equiv \sum_i (g_{ki} z_i / m \omega_k^2)$$

$x_{0k}^2$  terms nontrivial, but independent of  $m_k$ .  
(for strictly harmonic case)

$$\begin{pmatrix} H_1 & \Delta \\ \Delta & -H_2 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} \xi \\ \eta \end{pmatrix}$$

$$\begin{pmatrix} H & \Delta \\ \Delta & \epsilon \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\langle \psi_{\uparrow}^{\dagger}(r_1) \psi_{\downarrow}^{\dagger}(r_2) \rangle$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & H_1 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\langle \psi_{\uparrow}^{\dagger}(r_1) \psi_{\downarrow}^{\dagger}(r_2) \rangle$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\langle \psi_{\uparrow}^{\dagger}(r_1) \psi_{\downarrow}^{\dagger}(r_2) \rangle$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\langle \psi_{\uparrow}^{\dagger}(r_1) \psi_{\downarrow}^{\dagger}(r_2) \rangle$$

$$\left( \sum_k c_k a_{k\uparrow}^{\dagger} a_{-k\downarrow}^{\dagger} \right)^{N/2} |vac\rangle$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\left( \sum_k c_k a_{k\uparrow}^+ a_{-k\downarrow}^+ \right)^{N/2} |vac\rangle$$

$k\uparrow$

$$\langle \psi_{\uparrow}^+(r_1) \psi_{\downarrow}^+(r_2) \rangle$$



$$\begin{pmatrix} H_0 & \Delta \\ \Delta^\dagger & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\left( \sum_k c_k a_{k+}^\dagger a_{-k+}^\dagger \right)^{1/2} |vac\rangle$$

$$u_k |11\rangle + v_k |00\rangle$$

$\langle 11 |$   
 $\rangle$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\left( \sum_k c_k a_{k\uparrow}^\dagger \right) |c\rangle$$

$$u_k |11\rangle + v_k |00\rangle$$

$$\langle \psi_i^\dagger(r_i) \psi_i^\dagger(r_i) \rangle$$

$k \uparrow$

$$u_k a_{k\uparrow}^\dagger + v_k a_{-k\downarrow}$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\left( \sum_k c_k a_{k\uparrow}^+ a_{-k\downarrow}^+ \right)^{1/2} |vac\rangle$$

$$u_k |11\rangle + v_k |00\rangle$$

$$\langle \psi_{\uparrow}(r_1) \psi_{\uparrow}^{\dagger}(r_1) \rangle$$

$$k \uparrow \quad u_k^+ a_{k\uparrow}^+ + v_k a_{-k\downarrow} \left( \sum_{k'} c_{k'} a_{k'\uparrow}^+ a_{-k'\downarrow}^+ \right)$$

$$\begin{pmatrix} H_0 & \Delta \\ \Delta & -H_0 \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

$$\left( \sum_k c_k a_{k\uparrow}^\dagger a_{-k\downarrow}^\dagger \right)^{N/2} |vac\rangle$$

$$u_k |11\rangle + v_k |00\rangle$$

$$\langle \psi_\uparrow^\dagger(r_i) \psi_\uparrow^\dagger(r_i) \rangle$$

$k \uparrow$

$$u_k a_{k\uparrow}^\dagger + v_k a_{-k\downarrow}^\dagger \left( \sum_{k'} c_{k'} a_{k'\uparrow}^\dagger a_{-k'\downarrow}^\dagger \right)$$

Exact solution of TDSE for steady  
initial condition:

$$\left. \begin{aligned} \psi(x,t) &= \exp - i(E_0 - \frac{1}{2} m \omega^2 x_0^2) t / \hbar \cdot \\ &\exp - \frac{i m \omega^2}{\hbar} (x + x_0) x_0 \sin 2\omega t \cdot \\ &\exp - \frac{i m \omega^2}{4\hbar} x_0^2 \sin 2\omega t \cdot \\ \psi(x + x_0 (1 - \cos \omega t)) \end{aligned} \right\}$$

$$x_0(z) \equiv g z / m \omega^2$$

for single-qubit, single-mode case,  $x_0^2$  terms  
constant.

Many-qubit, many-mode case:

$$\prod_k \psi(x_k, t) \quad (\omega \rightarrow \omega_k)$$

$$x_{0k}\{z_i\} \equiv \sum_i (g_{ki} z_i / m \omega_k^2)$$

$x_{0k}^2$  terms nontrivial, but independent of  $m_k$ .  
(for strictly harmonic case)