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APPENDIX

EVALUATION OF DOUBLE PATH INTEGRATION

According to the calculation of the generating functional

$$\begin{aligned}\left\langle e^{ik(u_\tau - u_\sigma)}\right\rangle_{HS} &= g_{HS}(\tau,\sigma) \\ &= \int du_2 \int du'_2 \delta(u_2 - u'_2) \int du_1 \int du'_1 \rho(u_1, u'_1) \\ &\quad \cdot \exp\left\{\frac{i}{\hbar} m (u_t - u'_t)^T (v_D - \frac{\Omega}{2}\epsilon R_t)|_0^T\right\} \\ &\quad \cdot \int \mathcal{D}[u_t] \int \mathcal{D}[u'_t] \exp\left\{\frac{i}{\hbar}(S[u,f] - S[u',f'])\right\} \qquad (217)\end{aligned}$$

where the action function $S[u,f]$ is for an electron in the applied magnetic field in $-\hat{z}$ direction with the delta funxtion forces $f = \hbar k \delta(t-\tau) + g$ and $f' = \hbar k \delta(t-\sigma) + g$

;

$$S[u,f] = \int_0^T dt \left(\frac{m}{2}\bar{\dot{u}}_t \dot{u}_t + \frac{eB}{2c}\bar{\dot{u}}_t \epsilon u_t + \bar{u}_t f_t\right) \qquad (218)$$

Let us change the coordinates

$$u_t - u'_t = x_t, \qquad (219)$$

$$u_t + u'_t = X_t, \qquad (220)$$

then eq.(217) becomes, within the new coordinate in eq.(219) and (220),

$$\begin{aligned}g_{HS}(\tau,\sigma) &= \int dx_2 \int dX_2 \delta(x_2) \int dx_1 \int dX_1 \rho(x_1, X_1) \\ &\quad \cdot \exp\left\{\frac{i}{\hbar} m (v_D + \frac{\Omega}{2}\epsilon R_t)|_0^T\right\} \\ &\quad \cdot \int \mathcal{D}[x] \int \mathcal{D}[X] \exp\left\{\frac{i}{\hbar} S[x, X, f, f']\right\} \qquad (221)\end{aligned}$$

Using the initial density matrix

$$\rho(u_1, u_1') = (\pi)^{-1/2} \exp\left\{-\frac{m\Omega}{4\hbar}(u_1^2 + {u_1'}^2)\right\} \tag{222}$$

which is the density matrix for the harmonic oscillator at ground state. Then, on the transformed coordinate system, it takes into the form

$$\rho(x_1, X_1) = (\pi)^{-1/2} \exp\left\{-\frac{m\Omega}{8\hbar}(x_1^2 + X_1^2)\right\} \tag{223}$$

The transformed action is then become

$$\begin{aligned} S[x, X, f, f'] &= \frac{m}{2} X_t(\dot{x}_t + \frac{\Omega}{2}\epsilon x_t)|_0^T + \frac{m}{2}\int_0^T dtX - tg[x_t] \\ &+ \frac{1}{2}\int_0^T dt x_t(f_t + f_t') \end{aligned} \tag{224}$$

with the functional

$$g[x_t] = \ddot{x}_t - \Omega\epsilon\dot{x}_t - \frac{1}{m}(f_t - f_t'). \tag{225}$$

Then eq.(221) becomes

$$\begin{aligned} g_{HS}(\tau, \sigma) &= norm. \int dX_2 \int dx_2 \delta(x_2) \int dX_1 \int dx_1 e^{\frac{im}{\hbar} x_t (v_D + \frac{\Omega}{2}\epsilon R_t)|_0^T} \\ &\cdot \exp\left\{-\frac{m\Omega}{8\hbar}(x_1^2 + X_1^2) + \frac{im}{2\hbar} X_t(\dot{x}_t + \frac{\Omega}{2}\epsilon x_t)|_0^T\right\} \\ &\cdot \int \mathcal{D}[x] \int \mathcal{D}[X] \exp\left\{-\frac{i}{\hbar}\int_0^T dt \frac{m}{2} X_t g[x_t]\right\} \\ &\cdot \exp\left\{\frac{i}{2\hbar}\int_0^T dt x_t(f_t + f_t')\right\} \end{aligned} \tag{226}$$

Vernon[5] was shown that the path integration $\int \mathcal{D}[X_t]$ results to the constrain of the path x_t with the condition

$$g[x_t] = 0 = \ddot{x}_t - \Omega\epsilon\dot{x}_t - \frac{1}{m}(f_t - f_t'). \tag{227}$$

The solution of this equation ,$\tilde{x}_t$, will be used in the path integration $\int \mathcal{D}[x_t]$ and results to

$$\exp\left\{\frac{i}{2\hbar}\int_0^T dt\tilde{x}_t(f_t+f_t')\right\} \tag{228}$$

Its solution, with the boundary conditions at $x(t=T)=x_2$ and $\dot{x}(t=T)=\dot{x}_2$ becomes in the form

$$\begin{aligned}\tilde{x}_t &= x_2+\frac{\dot{x}_2}{\Omega/2}e^{-\frac{\Omega}{2}\epsilon(T-t)}sin(\frac{\Omega}{2}(T-t)\\ &-\frac{1}{m\Omega/2}\int_t^T dse^{\frac{\Omega}{2}\epsilon(t-s)}sin(\frac{\Omega}{2}(t-s))(f_t-f_s')\end{aligned} \tag{229}$$

which also show the relation

$$dx_1 = e^{\Omega\epsilon T}d\dot{x}_2. \tag{230}$$

After the double path integrations, $\int \mathcal{D}[x_t]\int \mathcal{D}[X_t]$, we get the result of eq.(228) in the form

$$\begin{aligned}g_{HS}(\tau,\sigma) &= norm.\int dX_2\int dx_2\delta(x_2)\int dX_1\int dx_1\delta(\dot{x}_2)\\ &\cdot\exp\left\{\frac{im}{\hbar}x_t(v_D+\frac{\Omega}{2}\epsilon R_t)|_0^T\right\}\\ &\cdot\exp\left\{-\frac{m\Omega}{8\hbar}(x_1^2+X_1^2)+\frac{im}{2\hbar}X_t(\dot{x}_t+\frac{\Omega}{2}\epsilon x_t)|_0^T\right\}\\ &\cdot\exp\left\{\frac{i}{2\hbar}\int_0^T dtx_t(f_t+f_t')\right\}.\end{aligned} \tag{231}$$

The dX_2 integration results to the delta function $\delta(\dot{x}_2)$ and the dX_1 integration results to the function

$$\exp\left\{-\frac{m}{\hbar\Omega/2}(\dot{x}_1-\frac{\Omega}{2}\epsilon x_1)(\dot{x}_1-\frac{\Omega}{2}\epsilon x_1)\right\}. \tag{232}$$

The dx_1 and dx_2 integrations on eq.(231) can be done with the delta functions $\delta(x_2)$ and $\delta(\dot{x}_2)$, change the integral dx_1 to $d\dot{x}_2$ by eq.(230) and then result to

$$
\begin{aligned}
g_{HS}(\tau,\sigma) \;=\; & norm.\exp\left\{-\frac{2iv_D}{\Omega\hbar}\int_0^T dte^{-\frac{\Omega}{2}\epsilon t}sin(\frac{\Omega}{2}t)(f_t - f_t')\right\} \\
& \cdot\exp\{-\frac{1}{m\Omega\hbar}\int_0^T dt\int_0^T dt'(f_t - f_t')e^{\frac{\Omega}{2})t-t')} \\
& \times\left(f_{t'}e^{-i\Omega(t-t')/2} - f_{t'}'e^{i\Omega(t-t')/2}\right)\}. \qquad (233)
\end{aligned}
$$

. The *norm.* will be put to be one for the fact that the generating function must become to be unity when the forces are zero.

VITA

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