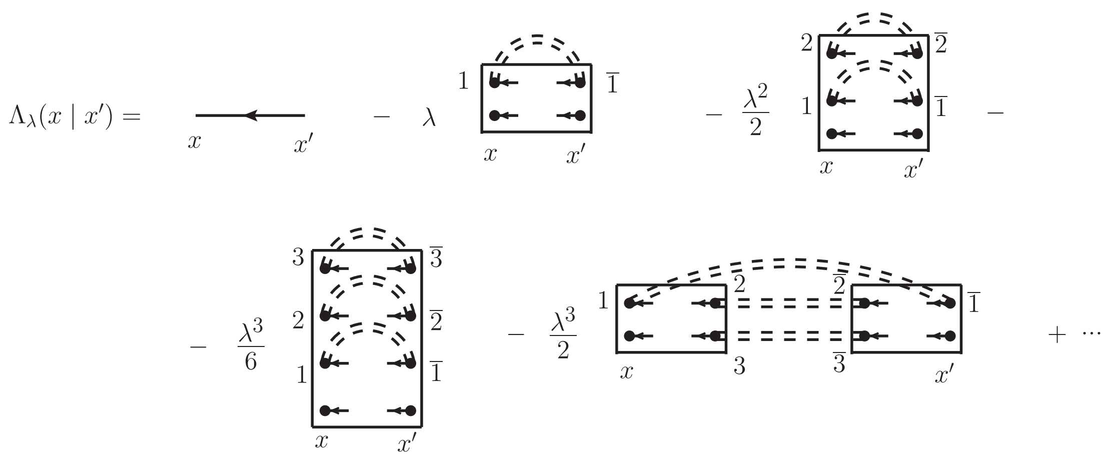

FIG. 2: The skeleton diagrams for correlation function Λ_λ. Double dashed lines depict the tunneling Green's functions T_λ and the rectangles depict the irreducible Green's functions.

III. THERMODYNAMIC POTENTIAL DIAGRAMS

The thermodynamic potential of the system is determined by the connected part of the mean value of the evolution operator [11,12]

$$F \;=\; F_0 - \frac{1}{\beta}\,\langle U(\beta)\rangle_0^c\,. \tag{14}$$

Let us consider a more general quantity first

$$F(\lambda) \;=\; F_0 - \frac{1}{\beta}\,\langle U_\lambda(\beta)\rangle_0^c\,, \tag{15}$$

and put then $\lambda = 1$.

By using the perturbation theory we have obtained the first orders of diagrams for $\langle U_\lambda(\beta)\rangle_0^c$, depicted in Fig. 3.

In order to obtain the better understanding of these diagrammatic contributions we examine the expression

$$\sum_{xx'} G_\lambda(x|x')\lambda t(\vec{x}' - \vec{x})\delta(\tau - \tau' - 0^+)\delta_{\sigma\sigma'}, \tag{16}$$

where double repeated indices suppose summation and integration. Consequently (16) is equal to

$$\begin{aligned} &-\ \beta \sum_{\vec{x}\vec{x}'}\sum_{\sigma} G_{\lambda\sigma}(\vec{x} - \vec{x}'|-0^+)\lambda t(\vec{x}' - \vec{x}) \\ &=\ -\lambda \sum_{\vec{k}\,\sigma}\sum_{\omega_n} \epsilon(\vec{k})G_{\lambda\sigma}(\vec{k}|i\omega_n)\exp(i\omega_n 0^+). \end{aligned} \tag{17}$$

Here we have carried out the integration by time.

From diagrammatic point of view equation (16) implies the procedure of locking of the external lines of propagators G_λ diagrams depicted on the Fig. 1 with the tunneling matrix element $t(\vec{x}' - \vec{x})$ and obtaining in such a way the diagrams without external lines similar with ones for $\langle U_\lambda(\beta)\rangle_0^c$ depicted on Fig. 3. These two series of diagrams differ by coefficients in front of them.

In expression (17) the coefficients $\frac{1}{n}$ before each diagram are absent, where n is the order of perturbation theory. These coefficients are present in Fig. 3. In order to restore these $\frac{1}{n}$ coefficients in (17) and obtain the coincidence with $\langle U_\lambda(\beta)\rangle_0^c$ series it is enough to integrate by λ the expression (17) and obtain:

$$-\sum_{\vec{x}\vec{x}'}\sum_{\sigma}\beta\int d\lambda t(\vec{x}' - \vec{x})G_{\lambda\sigma}(\vec{x} - \vec{x}'|-0^+). \tag{18}$$

The expression (18) displayed in a diagrammatic representation coincides exactly with mean value of the evolution operator:

$$\begin{aligned} \langle U_\lambda(\beta)\rangle_0^c \;=&\; -\sum_{\vec{x}\vec{x}'}\beta t(\vec{x}' - \vec{x}) \\ &\times \int_0^\lambda d\lambda' G_{\lambda'\sigma}(\vec{x} - \vec{x}'|-0^+). \end{aligned} \tag{19}$$

In Fourier representation we have

$$\langle U_\lambda(\beta)\rangle_0^c = -\int_0^\lambda d\lambda' \sum_{\vec{k}\,\sigma\omega_n} \epsilon(\vec{k})G_{\lambda'\sigma}(\vec{k}|i\omega_n)\exp(i\omega_n 0^+). \tag{20}$$

From (15) and (20) we obtain

$$\begin{aligned} F(\lambda) \;=&\; F_0 + \int_0^\lambda d\lambda' \sum_{\vec{k}\,\sigma}\frac{1}{\beta}\sum_{\omega_n}\epsilon(\vec{k}) \\ &\times\ G_{\lambda'\sigma}(\vec{k}|i\omega_n)\exp(i\omega_n 0^+). \end{aligned} \tag{21}$$

Using the definition (14), the equation (21) can be written in the form:

$$\begin{aligned} F(\lambda) \;=&\; F_0 + \int_0^\lambda \frac{d\lambda'}{\lambda'} \sum_{\vec{k}\,\sigma}\frac{1}{\beta}\sum_{\omega_n} T_{\lambda'}(k) \\ &\times\ \Sigma_{\lambda'}(k)\exp(i\omega_n 0^+). \end{aligned} \tag{22}$$