

Perturbation expansion

This is the propagator for a particle in a potential energy field $V(x, t)$.

$$K(b, a) = \int_{x_a}^{x_b} \exp \left[\frac{i}{\hbar} \int_{t_a}^{t_b} \left(\frac{m\dot{x}^2}{2} - V(x(t), t) \right) dt \right] \mathcal{D}x(t)$$

Factor the exponential.

$$K(b, a) = \int_{x_a}^{x_b} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_b} \frac{m\dot{x}^2}{2} dt \right) \exp \left(-\frac{i}{\hbar} \int_{t_a}^{t_b} V(x(t), t) dt \right) \mathcal{D}x(t)$$

Expand the second exponential as a power series.

$$K(b, a) = \int_{x_a}^{x_b} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_b} \frac{m\dot{x}^2}{2} dt \right) \left(1 - \frac{i}{\hbar} \int_{t_a}^{t_b} V(x(t), t) dt + \dots \right) \mathcal{D}x(t)$$

Hence

$$K(b, a) = K_0(b, a) + K_1(b, a) + \dots$$

where K_0 is a free particle propagator and

$$K_1(b, a) = -\frac{i}{\hbar} \int_{x_a}^{x_b} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_b} \frac{m\dot{x}^2}{2} dt \right) \int_{t_a}^{t_b} V(x(t_c), t_c) dt_c \mathcal{D}x(t)$$

Interchange the order of the integrals.

$$K_1(b, a) = -\frac{i}{\hbar} \int_{t_a}^{t_b} \int_{x_a}^{x_b} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_b} \frac{m\dot{x}^2}{2} dt \right) V(x(t_c), t_c) \mathcal{D}x(t) dt_c$$

Factor the exponential with respect to t_c .

$$K_1(b, a) = -\frac{i}{\hbar} \int_{t_a}^{t_b} \int_{x_a}^{x_b} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_c} \frac{m\dot{x}^2}{2} dt \right) \exp \left(\frac{i}{\hbar} \int_{t_c}^{t_b} \frac{m\dot{x}^2}{2} dt \right) V(x(t_c), t_c) \mathcal{D}x(t) dt_c$$

The two exponentials are free particle propagators.

$$\begin{aligned} \exp \left(\frac{i}{\hbar} \int_{t_a}^{t_c} \frac{m\dot{x}^2}{2} dt \right) &= K_0(x(t_c), t_c, x_a, t_a) \\ \exp \left(\frac{i}{\hbar} \int_{t_c}^{t_b} \frac{m\dot{x}^2}{2} dt \right) &= K_0(x_b, t_b, x(t_c), t_c) \end{aligned}$$

Hence

$$K_1(b, a) = -\frac{i}{\hbar} \int_{t_a}^{t_b} \int_{x_a}^{x_b} K_0(x(t_c), t_c, x_a, t_a) K_0(x_b, t_b, x(t_c), t_c) V(x(t_c), t_c) \mathcal{D}x(t) dt_c$$

The integral is over all possible paths $x(t)$ hence

$$-\infty < x(t_c) < \infty$$

Let $x_c = x(t_c)$ and transform the measure to dx_c instead of $\mathcal{D}x(t)$.

$$K_1(b, a) = -\frac{i}{\hbar} \int_{t_a}^{t_b} \int_{-\infty}^{\infty} K_0(x_c, t_c, x_a, t_a) K_0(x_b, t_b, x_c, t_c) V(x_c, t_c) dx_c dt_c$$