Pierre-Antoine Graham

Homework 2

Bindiya Arora and Dan Wohns
Quantum Mechanics

Perimeter Institute for Theoretical Physics
October 11, 2023

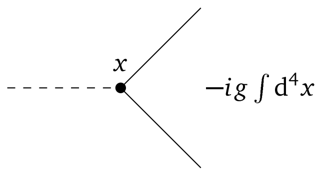
Contents

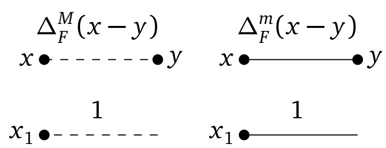
1 Two real scalars

(a) We are considering here perturbative results in the quantum field theory of two interacting real massive scalars φ, Φ with respective masses m and M. The lagrangian density describing this theory is

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \varphi)^2 - \frac{1}{2}m^2\varphi^2 + \frac{1}{2}(\partial_\mu \Phi)^2 - \frac{1}{2}M^2\Phi^2 - \frac{g}{2!1!}\Phi\varphi^2$$

where g descrives the coupling of the fields and is the parameter of our perturbative expansion. The position-space Feynman rules for perturbative computation of the interacting vacuum $|\Omega\rangle$ n-point functions $\langle\Omega| T\varphi(x_1)\cdots\Phi(x_k)\cdots\Phi(x_n)|\Omega\rangle$ for this theory are summed up graphically below:



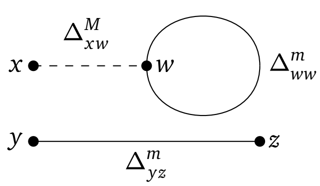


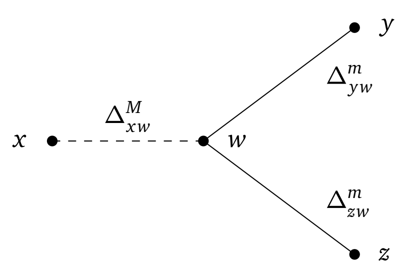
1. Every vertex in a diagram is associated to a four-position variable x. Its contribution to the symbolic representation of the amplitude is the integral $-ig\int d^4x$ acting on the propagators from the x vertex to other vertices.

2. Each vertex is the source of two full lines and a dashed line free Klein-Gordon respectively representing a φ Feynman propagator $\Delta_F^m(x-y)$ and a Φ Feynman propagator $\Delta_F^M(x-y)$ between points x and y (vertices or external points $x_1\cdots x_n$ of the expanded n-point function). Each edge of the diagram is symbolically represented as a multiplication by its associated Feynman propagator. In scalar field theory the external points contribute a trivial factor of 1 to the amplitude of the diagram.

3. Divide the amplitude by the symmetry factor of the diagram $S = 2/W$ where W is the number of wick contraction producing the same symbolic diagram expression. S is computed graphically as the order of the fixed end-points automorphism group of the diagram.

(b) The three-point function $G(x,y,z) = \langle\Omega| T\Phi(x)\varphi(y)\varphi(z)|\Omega\rangle$ has no $O(1)$ contributions because the number of contracted fields is odd at this order and no full Wick contractions can be formed: the vacuum is anihilated. At $O(g)$, we have the diagrams

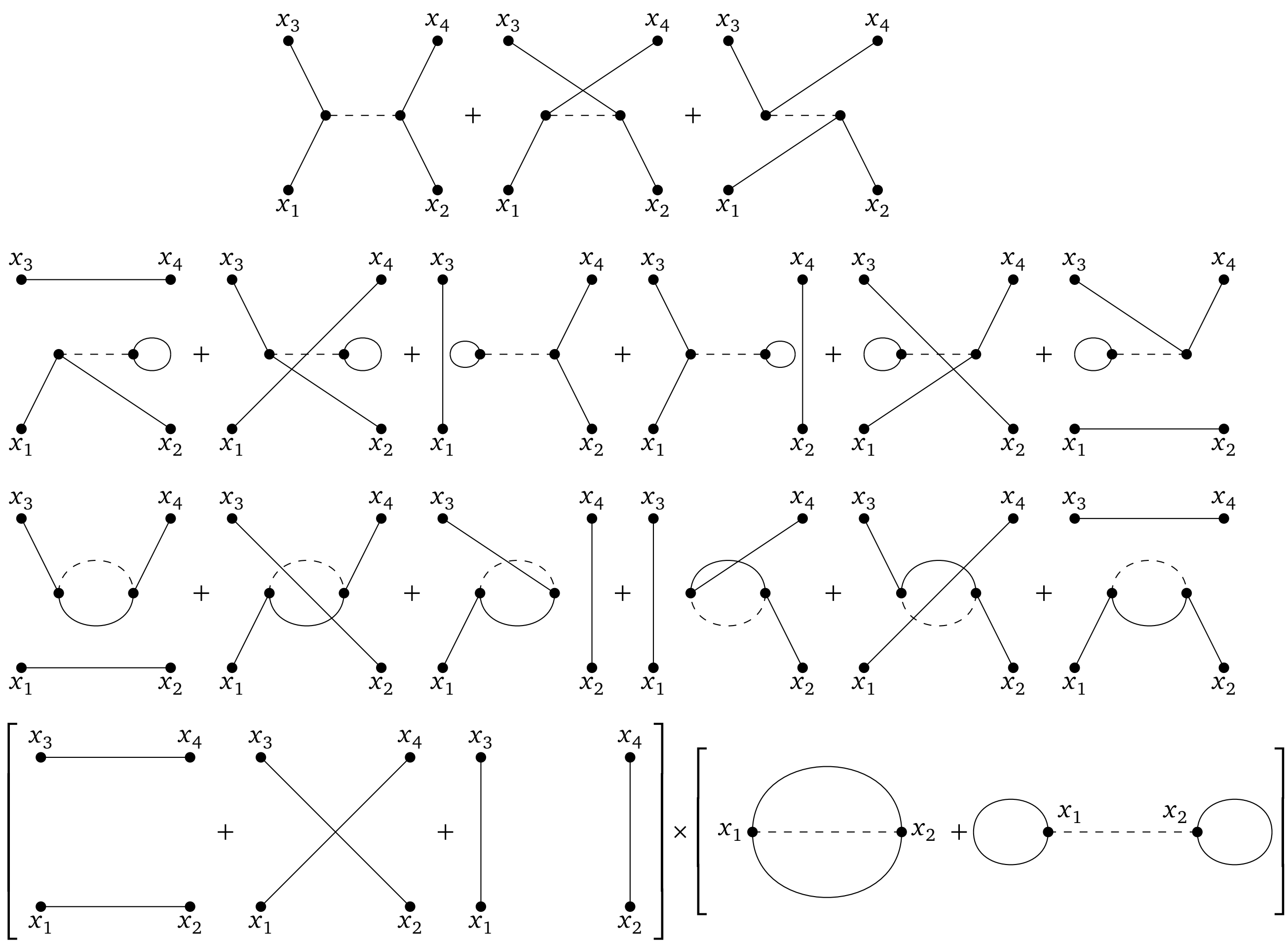




(c)

(d)

(e)



(f)

(g)

(h)

2 Acknowledgement

References

[1] *Wave packet, Wikipedia*. 2023. URL: https://en.wikipedia.org/wiki/Wave_packet.