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Relativistic Quantum Field Theory

Exercise 7

Problem 1: (*Wick-Theorem*)

Using the Wick theorem, calculate the following expressions

a) ${}_0\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\hat{\phi}^2(x_3^\mu)\}|0\rangle_0$

b) ${}_0\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\hat{\phi}^4(x_3^\mu)\}|0\rangle_0$

c) ${}_0\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\hat{\phi}^6(x_3^\mu)\}|0\rangle_0$

where $|0\rangle_0$ is the unperturbed vacuum of the free scalar field.

Problem 2: (ϕ^3-*theory*)

Consider a scalar field theory with the Lagrangian density

$$\mathcal{L} = \frac{1}{2}(\partial_\mu\phi)(\partial^\mu\phi) - \frac{m^2}{2}\phi^2 - \frac{\lambda}{3!}\phi^3 \,.$$

Draw all possible Feynman diagrams up to the order λ^2 and give the associated mathematical expressions for

a)
$$ {}_\lambda\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\}|0\rangle_\lambda $$

b)
$$ {}_\lambda\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\hat{\phi}(x_3^\mu)\}|0\rangle_\lambda $$

c)
$$ {}_\lambda\langle 0|\mathcal{T}\{\hat{\phi}(x_1^\mu)\hat{\phi}(x_2^\mu)\hat{\phi}(x_3^\mu)\hat{\phi}(x_4^\mu)\}|0\rangle_\lambda $$

d) Which of the diagrams are divergent?

e) Draw all Feynman diagrams in leading order in λ for two incoming particles with the four-momentum k_1^μ and k_2^μ and two outgoing particles with the four-momentum k_3^μ and k_4^μ and give the associated mathematical expression. All k_i^μ are different from each other.