\[
\int \frac{d^nq}{(2\pi)^n} \left( \frac{1}{(q^2 + 2qp - m^2 + i\epsilon)^r} \right) = i(-1)^r (p^2 + m^2)^{2-r}(4\pi)^{\epsilon-2} \frac{\Gamma(\epsilon + r - 2)}{\Gamma(r)}
\]
\[
\int \frac{d^nq}{(2\pi)^n} \left( \frac{q^\mu}{(q^2 + 2qp - m^2 + i\epsilon)^r} \right) = -i(-1)^r (p^2 + m^2)^{2-r}(4\pi)^{\epsilon-2} \frac{\Gamma(\epsilon + r - 2)}{\Gamma(r)} p^\mu
\]
\[
\int \frac{d^nq}{(2\pi)^n} \left( \frac{q^\mu q^\nu q^\alpha}{(q^2 + 2qp - m^2 + i\epsilon)^r} \right) = i(-1)^r (p^2 + m^2)^{2-r}(4\pi)^{\epsilon-2} \frac{\Gamma(\epsilon + r - 3)}{\Gamma(r)} \times [(\epsilon + r - 3)p^\mu p^\nu - \frac{1}{2}g^\mu\nu(p^2 + m^2)]
\]
\[
\int \frac{d^nq}{(2\pi)^n} \left( \frac{q^\mu q^\nu q^\alpha q^\beta}{(q^2 + 2qp - m^2 + i\epsilon)^r} \right) = i(-1)^r (p^2 + m^2)^{2-r}(4\pi)^{\epsilon-2} \frac{\Gamma(\epsilon + r - 4)}{\Gamma(r)} \times \left\{ (\epsilon + r - 3)(\epsilon + r - 4)p^\mu p^\nu p^\alpha p^\beta - \frac{1}{2}(\epsilon + r - 4)(g^\mu\nu p^\alpha p^\beta + g^\mu\alpha p^\nu p^\beta + g^\nu\beta p^\mu p^\alpha + g^\alpha\beta p^\mu p^\nu)(p^2 + m^2) + \frac{1}{4}(g^\mu\nu g^\alpha\beta + g^\mu\alpha g^\nu\beta + g^\nu\beta g^\mu\alpha)(p^2 + m^2)^2 \right\}
\]

where \( \epsilon \) (not to be confused with \( \epsilon \)) is a positive infinitesimal constant and \( \epsilon \) is related to the number of spacetime dimensions via

\[ g^{\mu\nu} g_{\mu\nu} = n = 4 - 2\epsilon. \]

In addition, we shall define

\[ \int \frac{d^nq}{(2\pi)^n} \left( \frac{1}{q^2} \right)^r \equiv 0, \]

which corresponds to setting \( p^2 = m^2 = 0 \) in the first integral above under the assumption that \( \epsilon < 2 - r \). However, in the dimensional regularization procedure, we shall adopt the above definition for all \( r \).

We can expand about \( \epsilon = 0 \) by using

\[ \Gamma(-N + \epsilon) = \frac{(-1)^N}{N!} \left[ \frac{1}{\epsilon} + \psi(N + 1) + \mathcal{O}(\epsilon) \right], \]
where \( N \) is a non-negative integer, \( \psi(x) \equiv \Gamma'(x)/\Gamma(x) \) with \( \Gamma'(x) \equiv d\Gamma(x)/dx \),

\[ \psi(1) = -\gamma, \quad \psi(N + 1) = -\gamma + \sum_{k=1}^{N} \frac{1}{k}, \]

and \( \gamma = -\Gamma'(1) = 0.5772 \cdots \) is the Euler-Mascheroni constant. If the \( \mathcal{O}(\epsilon) \) terms are needed, then one must use \( x\Gamma(x) = \Gamma(x + 1) \) until \( \Gamma(1 + \epsilon) \) is reached, and then use

\[ \Gamma(1 + \epsilon) = 1 - \epsilon + \sum_{k=2}^{\infty} \frac{(-\epsilon)^k}{k!} \zeta(k), \]

where \( \zeta(k) \) is the Riemann zeta function.

When fermions are involved, we need to consider the Dirac matrix algebra in \( n \)-dimensions. The Dirac gamma matrices are denoted by \( \gamma^0, \gamma^1, \gamma^2, \ldots, \gamma^{n-1} \). The \( n \)-dimensional analog of \( \gamma_5 \) is somewhat problematical, although we shall treat it as anticommuting with all the other gamma matrices. The following \( n \)-dimensional gamma matrix relations must be used:

1. \( \{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu} \)
2. \( \{\gamma^\mu, \gamma_5\} = 0 \)
3. \( (\gamma_5)^2 = 1 \)
4. \( \gamma^\mu \gamma^\mu = n \)
5. \( \gamma^\mu \gamma^\alpha \gamma^\mu = (2 - n)\gamma^\alpha \)
6. \( \gamma^\mu \gamma^\alpha \gamma^\beta \gamma^\mu = 4g^{\alpha\beta} + (n - 4)\gamma^\alpha \gamma^\beta \)
7. \( \gamma^\mu \gamma^\alpha \gamma^\beta \gamma^\rho \gamma^\mu = -2\gamma^\rho \gamma^\beta \gamma^\alpha + (4 - n)\gamma^\alpha \gamma^\beta \gamma^\rho \)

8. Trace formulae are unchanged. In particular, \( \text{Tr} \gamma^\mu \gamma^\nu = 4g^{\mu\nu} \).

The 4 in the last trace formula is purely conventional. However, note that it is crucial to use \( g^{\mu\nu}g_{\mu\nu} = n \) in all calculations in \( n \)-dimensions before taking the \( \epsilon \to 0 \) limit.

Finally, we record some of the Feynman parameter formulae:

\[ \frac{1}{A^\alpha B^\beta} = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \int_0^1 dx \frac{x^{\alpha - 1}(1 - x)^{\beta - 1}}{[xA + (1 - x)B]^\alpha + \beta} \]

\[ \frac{1}{A^\alpha B^\beta C^\delta} = \frac{\Gamma(\alpha + \beta + \gamma)}{\Gamma(\alpha)\Gamma(\beta)\Gamma(\gamma)} \int_0^1 x \int_0^1 dy \frac{x^{\alpha + \beta + \gamma - 2} y^{\alpha - 1}(1 - x)^{\beta - 1}(1 - y)^{\delta - 1}}{[xyA + x(1 - y)B + (1 - x)C]^\alpha + \beta + \gamma} \]

and more generally,

\[ \frac{1}{A_1^{\alpha_1} A_2^{\alpha_2} \cdots A_N^{\alpha_N}} = \frac{\Gamma(\alpha_1 + \alpha_2 + \cdots + \alpha_N)}{\Gamma(\alpha_1)\Gamma(\alpha_2)\cdots \Gamma(\alpha_N)} \int_0^1 dx_1 \int_0^1 dx_2 \cdots \int_0^1 dx_N \delta \left( \sum_{j=1}^{N} x_j - 1 \right) \times \frac{x_1^{\alpha_1 - 1} x_2^{\alpha_2 - 1} \cdots x_N^{\alpha_N - 1}}{(x_1A_1 + x_2A_2 + \cdots + x_NA_N)^{\alpha_1 + \alpha_2 + \cdots + \alpha_N}} \]