Glossary of Symbols for

Student Friendly Quantum Field Theory

This glossary has been compiled by Bill Daniel and is posted here for the benefit of other readers.

Thank you, Bill!

Symbol Glossary

Page numbers (second edition, and in all but a few cases the first edition as well) containing the introduction, definition, or extensive use of a symbol are shown in parentheses. Pages with considerable development of the concept are given in **bold**.

Non-alphanumeric Symbols

∂slash = $\gamma^\mu \partial_\mu$ = slash notation applied to the partial derivative. (88)

$\partial_\mu \phi = \phi_{,\mu} = \frac{\partial}{\partial x^\mu}$ = alternative notations for the covariant form of the partial derivative. (16)

$\partial^\mu \phi = \phi^{,\mu} = \frac{\partial}{\partial x_\mu}$ = alternative notations for the contravariant form of the partial derivative. (16)

$\partial_\mu \partial^\mu = \partial^\mu \partial_\mu = \Box^2$ = alternative notations for the d'Alembertian operator. (42, **49**)

{ , } = Poisson bracket. (3, **24**)

[,] = commutator. (4)

$[\ ,\ ]_+$ = anticommutator. (66)

Roman Alphabet Symbols

A

A = electromagnetic 3-potential. (135)

A = a general operator (as on 325), term (as on 463), or normalization factor (as on 502).

Aslash = $\gamma^\mu A_\mu$ = slash notation applied to vector potential. (195)

$A^\mu(\mathbf{x}, t) = (\Phi, \mathbf{A})$ = electromagnetic 4-potential. (138, 183, 402)

$A^{\mu+}$ = total photon particle lowering operator field. (149)

$A^{\mu-}$ = total photon particle raising operator field. (149)

$A(\Lambda, m) = -\frac{3m}{8\pi^2} \ln\left(\frac{\Lambda}{m}\right)$ = infinite term (as $\Lambda \to \infty$) in $\Sigma(p)$. (323, **324**)

$A'(k, \Lambda) = -2 b_n \ln\left(\frac{k}{\Lambda}\right)$ = infinite term (as $\Lambda \to \infty$) in $\Pi^{\mu\nu}(k)$. (324, 383)

$A^e_\mu(\mathbf{x})$ = the static external electromagnetic potential represented by the photon in the Feynman diagram used in the calculation of the e^- magnetic moment. (415, 431a)

$A^\alpha_e(\mathbf{x})$ or $A^\alpha_e(\mathbf{k})$ = The same as $A^e_\mu(\mathbf{x})$ above. This slightly different (contravariant) notation is used for the static external electromagnetic potential of a "point charge" (such as an atomic nucleus) for Rutherford scattering in position or momentum space. (478)

$A^e_{\mathbf{k}''\mu}(\mathbf{x})$ and $A^{\dagger e}_{\mathbf{k}''\mu}(\mathbf{x})$ = factors in the expansion for $A^e_\mu(\mathbf{x})$. (431a)

a = parameter in a "useful relation" for Feynman parametrization. (378)

a_n = parameter in a "useful relation" for Feynman parametrization (n = 0, 1, ...). (378)

$a(\mathbf{k})$ = scalar particle destruction operator. (50)

$a^\dagger(\mathbf{k})$ = scalar particle creation operator. (50)

$a^\mu(x, z, p, p')$ = shorthand symbol used in the derivation of $\Lambda^\mu(p, p')$. (394)

B

B = magnetic 3-vector field. (135)

B = a general operator (as on 325), or term (as on 463).

$B(\Lambda) = L(\Lambda) = -\frac{1}{8\pi^2}\ln(\Lambda)$ = infinite term (as $\Lambda\to\infty$) in $\Sigma(p)$. (323, **324**)
b = parameter in a “useful relation” for Feynman parametrization. (378)
b = scattering impact parameter (perpendicular distance between the velocity vector of the incoming particle beam and a parallel radius from the potential source). (438)
$b(\mathbf{k})$ = scalar antiparticle destruction operator. (50)
$b^\dagger(\mathbf{k})$ = scalar antiparticle creation operator. (50)
b_n = factor accounting for contributions to $e(p)$ from other particle/antiparticle pairs beyond the photon $\left(b_1 = \frac{1}{12\pi^2}\right)$. (313-314)

C
c = parameter in a “useful relation” for Feynman parametrization. (378)
$c_r(\mathbf{k})$ = spinor particle destruction operator. (103)
$c_r{}^\dagger(\mathbf{k})$ = spinor particle creation operator. (103)

D
D = number of dimensions of space to be integrated over - not necessarily an integer. (374, **385-391**)
$D_F{}^{\mu\nu}(x-y)$ = photon Feynman 4-position space propagator. (150)
$D_F{}^{\mu\nu}(k)$ = photon Feynman 4-momentum space propagator. (150)
$D^{\text{Mod}}_{\substack{2\text{ nd}\\ F\,\mu\nu}}(k) = D_{F\,\mu\nu}(k)\left(1 - e_0{}^2\,\Pi_c\right)$ = convergent (“Mod”) part of tree level $D_{F\,\mu\nu}(k)$ through second order terms in the expansion. (308)
$D^{e_0\,\text{Mod}}_{\substack{2\text{ nd}\\ F\,\mu\nu}}(k)$ = convergent part of the photon propagator $D_{F\,\mu\nu}(k)$ using the bare charge (“e_0”) through second order terms in the expansion. (347)
$D^{\mu\nu\pm}(x-y)$ = commutator form of vector particle/antiparticle field solution. (160)
$D_\nu = \partial_\nu - i\,e\,A_\nu$ = gauge covariant derivative. (297)
$\mathcal{D}\,x(t)$ = differential element of functional integration. (490)
$d_r(\mathbf{k})$ = spinor antiparticle destruction operator. (103)
$d_r{}^\dagger(\mathbf{k})$ = spinor antiparticle creation operator. (103)

E
$\mathbf{E}$ = electric field 3-vector. (135)
$E_\mathbf{k} = \omega_\mathbf{k}$ = energy or angular frequency of a wave with wave number $\mathbf{k}$. (43)
e = measured electron charge. Prior to page 307 this symbol is used for the “bare charge,” e_0.
$e(p)$ = measured charge on the electron as a function of energy p. (311-315)
e_0 = bare charge on the electron, i.e., the charge that would result from consideration of only the tree-level diagram. (307)
$e^-{}_{\mathbf{p},r}$ = electron with 3-momentum $\mathbf{p}$ and spin state r. (217)

F
$F^{\mu\nu}$, $F_{\mu\nu}$ = electromagnetic field tensor. (138, 288)
$F_i\left(k_\mu{}^2\right)$ = form factors ($i = 1,\ 2$ or $A,\ B$) in the derivation of the second order (in e) magnetic moment of the electron. (421)
$F[x(t)] = F[x]$ = a functional of the function x (x is itself a function of independent variable t). In our case, usually $F\left[L\left(x,\ \dot{x},\ t\right)\right] = \int_{t_a}^{t_b} L\,dt = S$, where L is the Lagrangian and S is the action. (489)
$|F\rangle = \sum_f S_{f\,i}\,\left|f\right\rangle$ = general final state. (196)
$f(\theta)$ = function whose squared norm is the NRQM scattering differential cross section. (439)
$f_b = n_b\,v_b$ = flux of the incident beam in a scattering experiment. (435)
$f_{\alpha,\beta,\gamma,\ldots\zeta}$ = factors in the nested convolution integral expansion of $U(i,\ f;\ T)$. (503)
$|f\rangle$ = final eigenstate whose probability amplitude is $S_{f\,i}$. (196)

G

$G_n,\ G_a,\ G_b$ = parts of $\Lambda_c^\mu(p,\ p')$. (424)
g = gyromagnetic ratio or "g-factor". (412)
$g_{\mu\nu}$ = (In this text) Minkowski metric tensor, covariant metric, or metric. (16, 34)
$g^{\mu\nu}$ = inverse of metric tensor, contravariant metric (in this text $g^{\mu\nu} = g_{\mu\nu}$). (16, 34)

H

$\mathcal{H}$ = Hamiltonian density operator. (18)
$H = \int \mathcal{H}\, d^3 x$ = Hamiltonian operator.
H^I = Hamiltonian in interaction picture. (191)
H^H = Hamiltonian in Heisenberg picture. (28)
H^S = Hamiltonian in Schrödinger picture. (28)
H_f^s = Hamiltonian of field with spin = s and type = f, (f = 0 indicates "free", f = I indicates "interaction"). (49, 190)
$\mathcal{H}_f^s$ = Hamiltonian density of field with spin = s and type = f, (f = 0 indicates "free", f = I indicates "interaction"). (49, 190, **199**)

I

$I_n^{\mu\nu}$ = subintegrals of $\Pi^{\mu\nu}(k)$; (n = 1, 2 in cutoff regularization; n = 1, 2, 3 in Pauli-Villars regularization). (380)
$| i\rangle$ = initial eigenstate in probability amplitude $S_{f\,i}$ calculation. (196)

J

J = part of $\Lambda_c^\mu(p,\ p')$. (424)
j = 3-current density. (May be any current. In QM, often probability current.) (45, 46)
$\mathbf{j}_{\text{charge}}$ = 3-electric current density. (183)
$j^\mu = \begin{pmatrix} \rho \\ \mathbf{j} \end{pmatrix}$ = 4-current density. (45)

K

k = shorthand for k^μ. Occasionally and temporarily, for notational convenience, $k = |\mathbf{k}|$. (389)
k = virtual fermion 4-momentum in a Feynman diagram or loop integral; energy level of an interaction. (224)
k = wave number 3-vector of an incoming fermion. (43)
k′ = wave number 3-vector of an outgoing fermion. (225)
$k_i = \frac{2\pi}{\lambda_i}$ = wave number 3-vector components. (43)
k_ν = 4-momentum of the external photon in the second order (in e) calculation of the magnetic moment of the electron. (420)

L

$\mathcal{L}$ = Lagrangian density. (31)
$L = L\left(q_i,\ \dot{q}_i,\ t\right) = \int \mathcal{L}\, d^3 x$ = Lagrangian operator. (17)
$\mathcal{L}_f^s$ = Lagrangian density of field with spin = s and type = f (f = 0 indicates "free", f = I indicates "interaction"). (49, 78)
$L(\Lambda) = B(\Lambda) = -\frac{1}{8\pi^2}\ln(\Lambda)$ = infinite term (as $\Lambda \to \infty$) in $\Lambda^\mu(p,\ p')$. (323, **324**)
$l^\pm$ = lepton or antilepton. (463)

M

$\mathcal{M} = \sum_{n=1}^{\infty} \mathcal{M}^{(n)}$ = total Feynman amplitude of a specified interaction. (223)
$\mathcal{M}^{(n)}$ = sum of amplitudes from all Feynman diagrams of order n in e. (223)
$\mathcal{M}^{(n)\,\mu\,\nu\,\eta\,\cdots}$ = n^{th} order (in e) Feynman amplitude for an interaction involving one or more initial or final photons (the number of

photons being the number of Greek letter superscripts). (323, 461)

$\mathcal{M}^{(n)}_{m\,m}$ = n^{th} order (in e) amplitude associated with the single vertex Feynman diagram used to calculate the magnetic moment of the e^-. (416, **421**)

$\mathcal{M}^{(n)}_{T\,i-j}$ = amplitude to n^{th} order (in e) for interaction type, T (T = C for Compton; T = B for Bhabha or Møller); fundamental kind of tree diagram, i (i = 1, 2 for Compton or Bhabha, or i = 3, 4 for Møller); and sub-kind, j (j is not used in the tree level case when n = 2; j = 1, 2, ..., 11, for example, for Bhabha scattering of order n = 4). (259)

$\mathcal{M}^{(2)}_{T\,i\ e_0\,\text{Mod},\,2\,\text{nd}}$ = second order (in e_0) convergent (“Mod”) part of $\mathcal{M}^{(2)}_{T\,i}$ amplitude using the bare charge (“e_0”). (346)

$\mathcal{M}^{(2)}_{T\,i\ \text{Mod},\,2\,\text{nd}}$ = second order (in e) convergent amplitude above with e_0 replaced by $e(k)$. (351)

m = measured (renormalized) mass. Prior to page 307 this symbol is used for the “bare mass,” m_0. (307, 312)

m_e = measured mass of the electron.

m_0 = bare mass, i.e., lepton mass that would result from consideration of only the tree-level diagram. (307)

N

N = normal ordering operator. (203)

$N(A^\mu)$ = total photon particle number. (149)

$N_a(\mathbf{k})$ = number operator for scalar particles of 3-momentum **k**. (54, 55)

$N_b(\mathbf{k})$ = number operator for scalar antiparticles of 3-momentum **k**. (54, 55)

N_c = normal ordering including (anti-)commutation relations operator. (203)

$N_r(\mathbf{p})$ = number operator for spinor particles of 3-momentum **p**, spin r. (108)

$\overline{N}_r(\mathbf{p})$ = number operator for spinor antiparticles of 3-momentum **p**, spin r. (108)

N_t = number of particles in a scattering target. (435)

N_f = number of final states for a scattered particle. (443)

$d\,N_f$ = number of final states of a scattered particle with 3-momentum, **p**, such that, $\mathbf{p}_f \leq \mathbf{p} \leq \mathbf{p}_f + d^3\,\mathbf{p}_f$. (443, **455**)

$N^{\mu\nu}(p,\ k)$ = subterms of $\Pi^{\mu\nu}(k)$. (389, 393)

$N^{\mu\nu}_i$ = subterms of $N^{\mu\nu}$ (i = 1, 2, 3). (390)

$n_a(\mathbf{k})$ = eigenvalue of $N_a(\mathbf{k})$ = number of scalar particles of 3-momentum **k**. (55)

$n_b(\mathbf{k})$ = eigenvalue of $N_b(\mathbf{k})$ = number of scalar antiparticles of 3-momentum **k**. (55)

$n_r(\mathbf{p})$ = eigenvalue of $N_r(\mathbf{p})$ = number of spinor particles of 3-momentum **p**, spin r. (108)

$\overline{n}_r(\mathbf{p})$ = eigenvalue of $\overline{N}_r(\mathbf{p})$ = number of spinor antiparticles of 3-momentum **p**, spin r. (108)

n_b = beam particle density in a scattering experiment. (435)

n_t = particle density in a scattering target. (434)

O

O = a general operator. (25)

$O(x)$ = “big O” notation indicating higher order terms in x.

$\overline{O}$ = expectation value of operator O. (25)

O^H = operator O in the Heisenberg picture. (26)

O^S = operator O in the Schrödinger picture. (26)

O^I = operator O in the Interaction picture. (188, 191-193)

P

P = 3-momentum operator. (113)

P^μ = 4-momentum of a system of particles. (16)

p = shorthand for p^μ. (16, 389); energy level of an interaction. (230)

p = parameter in standard integrals useful in regularization. (375)

p = 3-momentum of an incoming lepton. (43)

p′ = 3-momentum of an outgoing lepton. (225)

$\mathbf{p}'$ = 3-momentum in a primed coordinate system. (126)
$\mathcal{p}^i$ = components of physical 3-momentum density. (23)
$p_i = -p^i = \int \mathcal{p}_i \, d^3x$ = covariant components of 3-momentum of a single lepton. (17, **23**)
$p_\mu = \begin{pmatrix} E \\ -\mathbf{p} \end{pmatrix}$ = covariant 4-momentum of single lepton (16, 43)
$p^\mu = \begin{pmatrix} E \\ \mathbf{p} \end{pmatrix}$ = contravariant 4-momentum of single lepton. (16, 43)
p^0 = used post page 445 for E. For elastic collisions, $p^0 = E = KE$, i.e., all energy is kinetic. (445)
$p_E = +\sqrt{E^2 + \mathbf{p}^2}$ = Wick rotated 4-momentum. (376)

Q

$Q = \int s^0 \, d^3x$ = charge operator. (64, 111, 175)
Q_a = charge of a particle pair in units of e_0 used in the calculation of b_n. (314)
q = parameter in standard integrals useful in regularization. (386)
$q = p - kz$ = variable used in derivation of $\Pi^{\mu\nu}(k)$ in dimensional regularization. (389)

R

$r(x, z, p, p')$ = shorthand symbol used in the derivation of $\Lambda^\mu(p, p')$. (394)
r (as a subscript) = spin state for spinors. (89); = polarization state for photons. (146) (r =1, 2)

S

$\mathbf{S}$ = spin 3-vector. (99)
$S = \int L \, dt$ = action. (18)
S = time ordered infinite spacetime S_{oper}. (201)
$S_F(x - y)$ = Feynman position space spinor propagator. (118-**121**)
$S_F(p)$ = Feynman 4-momentum space spinor propagator. (121, 312)
$S_F^{2\text{nd}}(p)$ = approximation to $S_F(p)$ through second order (in α) terms in the expansion (14-4). (343)
$S_F^{2\text{nd}\ e_0\text{Mod}}(p + k) = S_F(p + k)\left(1 - e_0{}^2\,\Sigma_c\right)$ = convergent part of $S^{2\text{nd}}_F(p + k)$. (346)
S_{fi} = transition amplitude for transition from initial eigenstate $|i\rangle$ to final eigenstate $|f\rangle$; element of the S-matrix. (195)
S_{Fi} = transition amplitude for all final scattered states $|f\rangle$ with the same initial state $|i\rangle$. (443)
$d\,S_{Fi}$ = differential S_{Fi} within a solid angle $d\Omega$ (at polar angle θ, for $0 \le \phi \le 2\pi$). (443)
S_i = NRQM spin operator. (94)
$S^{(n)}$ = the n^{th} term of the Dyson expansion of the S operator. (216)
$S^{(n)}{}_m$ = the m^{th} sub-term of the n^{th} term of the Dyson expansion of the S operator. (217)
$S^{(n)}_{\text{mm}} = n^{\text{th}}$ order (in α) S operator associated with the single vertex Feynman diagram used to calculate the magnetic moment of the e^-. (415)
S_{oper} = an operator whose expectation value for transition from initial eigenstate $|i\rangle$ to final eigenstate $|f\rangle$ is S_{fi}; $S_{fi} = \langle f \,|\, S_{\text{oper}} \,|\, i\rangle$. (196-197)
$S^\pm$ = anti-commutator form of spinor particle/antiparticle field solution. (119-120)
s = parameter in standard integrals useful in regularization. (375)
$s^\mu = q\,j^\mu$ = charge density operator. (63)

T

T = time ordering operator. (72)
T_c = time ordering including (anti-)commutation relations operator. (205)
$t^\mu(x, z, p, p')$ = shorthand symbol used in the derivation of $\Lambda^\mu(p, p')$. (394)

U

U = general unitary operator. (26, **27**)
$U(n)$ = unitary group of dimension n. (296)
$U(\psi_i,\ \psi_f;\ T)$ = the amplitude in the path integral formulation for a transition from state ψ_i to ψ_f after a finite time T. Note that as $T \to \infty$, $U \to S_{f\,i}$, the transition amplitude between the same two states in the canonical quantization formulation of QFT. (491)
$u_r(\mathbf{p})$ = spinors (r = 1, 2). (89)
$\overline{u}_r(\mathbf{p})$ = adjoint spinors (r = 1, 2). (91)

V

V = volume. (45)
V_t = volume of the scattering target. (434)
$V(\mathbf{x})$ = electromagnetic potential field. (406)
$\tilde{V}(\mathbf{k})$ = Fourier transform of $V(\mathbf{x})$. (406)
$V(r)$ = radial (Coulomb) potential. (408)
v_b = scattering beam velocity (target stationary). (435)
$v_{\text{rel}} = v_1 - v_2$ = relative co-linear velocity between two particle beams. (453)
$v_r(\mathbf{p})$ = antispinors (r = 1, 2). (89)
$\overline{v}_r(\mathbf{p})$ = adjoint antispinors (r = 1, 2). (91)

X

$X^{\eta\rho}(k,\ \Lambda)$ = a portion of the expression for Feynman amplitude with integration limits of $\pm\Lambda$. (308)
$x_\mu = \begin{pmatrix} t \\ -X_i \end{pmatrix}$ = covariant components of 4D position in Minkowski coordinate space. (15)
$x^\mu = \begin{pmatrix} t \\ X_i \end{pmatrix}$ = contravariant components of 4D position in Minkowski coordinate space. (15)
x = shorthand for x^μ. (16)
x_i and x_f = initial and final 1-dimensional positions of a particle in the path integral development. Note that x_i is also denoted x_0 and x_f is denoted x_n, where n is the number of spatial slices. (502)

Z

$Z_\gamma^{2\,nd} = 1 - e_0^2\, A'$ = shorthand symbol associated with the photon in Feynman amplitude expression through second order (in α) terms in the expansion. (344)
$Z_f^{2\,nd} = \frac{1}{1+e_0^2\, B} \approx 1 - e_0^2\, B$ = shorthand symbol associated with a fermion in Feynman amplitude expression through second order (in α) terms in the expansion. (344)
$Z_V^{2\,nd} = 1 + e_0^2\, L$ = shorthand symbol associated with a vertex in Feynman amplitude expression through second order (in α) terms in the expansion. Because $B = L$, $Z_V^{2\,nd} = \frac{1}{Z_f^{2\,nd}}$. (344)
$Z_\gamma^{nth} = \frac{1}{1+e_0^2\, A'_{nth}}$ = shorthand symbol associated with the photon in Feynman amplitude expression through n^{th} order (in α) terms in the expansion. (360)
$Z_f^{nth} = \frac{1}{1+e_0^2\, B_{nth}}$ = shorthand symbol associated with a fermion in Feynman amplitude expression through n^{th} order (in α) terms in the expansion. (360)
$Z_V^{nth} = 1 + e_0^2\, L_{nth}$ = shorthand symbol associated with a vertex in Feynman amplitude expression through n^{th} order (in α) terms in the expansion. Because $B_{nth} = L_{nth}$, $Z_V^{nth} = \frac{1}{Z_f^{nth}}$. (360)
$z,\ z_n$ = dummy integration variables in Feynman parametrization. (378)

Greek Alphabet Symbols

A

$\alpha = \frac{e^2}{4\pi}$ = fine structure "constant"; electromagnetic coupling "constant." Prior to page 307 this symbol is used for the "bare coupling constant," α_0. (215, 307, 311); at large distances (low energies) $\alpha \approx \frac{1}{137}$. (317)

$\alpha(p) = \alpha(\mu)$ = running QED coupling "constant" at energy p or μ. (316)

$\alpha(x^\mu)$ = gauge that preserves local invariance of $\mathcal{L}$. (326, 178, 294)

α_0 = bare coupling constant; i.e., the coupling constant that would result from consideration of only tree-level diagrams. (307)

B

$\beta(p,\ b_n)$ = beta function that specifies the energy scale dependence of α and e. (317)

Γ

$\Gamma(n)$ = gamma function (n need not be an integer). Note: $\Gamma(n) = (n-1)!$ if n is an integer. (375)

Γ_s = all of the Feynman amplitude $\mathcal{M}$ except for the external fermions - used in spin sum calculations (s = 1, 2 for spin states, or no subscript for their sum). (459)

$\tilde{\Gamma} = \gamma^0\, \Gamma^+\, \gamma^0$ = shorthand symbol used in spin sum calculations. (459)

$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$ = Lorentz factor. (33)

γ ($\approx$ 0.5772) = Euler-Mascheroni constant. (387)

$\gamma_{\mathbf{k},\, s}$ = photon with wave vector **k** and spin state s. (217)

γ^μ = Dirac matrices. (87)

$\gamma^\mu_{\alpha\beta} = \gamma^\mu$ with spinor indices specified. (223)

$\gamma^\mu_{2\,\mathrm{nd}}$ = vertex modification through second order (in α) terms in the expansion (13-13). (344)

$\gamma^\mu_{e_0\,\mathrm{Mod}\atop 2\,\mathrm{nd}} = \gamma^\mu + {e_0}^2\, \Lambda^\mu_c$ = convergent part of tree level γ^μ through second order (in α) terms in the expansion. (346)

Δ

$\Delta_F\,(x - y)$ = scalar Feynman 4-position space propagator. (70-**77**)

$\Delta_F\,(k)$ = scalar Feynman 4-momentum space propagator. (78)

$\Delta^\pm$ = commutator form of scalar particle/antiparticle field solution. (74)

$\delta^{(4)}$ = 4D delta function. (218, 239)

$\delta\, m$ = change in mass from bare mass to give measured mass. (312)

E

ϵ = variable in "leading log" approximation: $f(\epsilon) = \ln(\Lambda' + \epsilon) \approx \ln(\Lambda')$ for $\epsilon \ll \Lambda'$ (378)

${\epsilon_r}^\mu$ = photon 4-polarization vector. (141)

ϵ^μ_s ($\propto r\, A^\mu$) = solution to the charge-free Coulomb field equation. (403)

$\epsilon^{2\,\mathrm{nd}}_\mu$ = photon external line through second order (in α) terms in the expansion (13-13). (344)

Z

ζ_μ: defined as $\zeta_0 = -1$; $\zeta_{1,\,2,\,3} = 1$. (142)

H

η = dimension adjustment parameter in dimensional regularization. (374, **385**)

Θ
θ = polar scattering angle. (436)

Λ
Λ = parameter that is taken to be finite in the regularization process and later allowed $\to\infty$. (306, 319, 323)
Λ = parameter in standard integrals useful in regularization. (375)
$\Lambda^{\mu}(p,\ p')$ = vertex loop correction integral. (323, **397**)
$\Lambda_c^{\mu}(p,\ p')$ = convergent part of vertex loop correction integral. (323, **396**)
$\Lambda_i^{\mu}(p,\ p')$ = subterm in the derivation of $\Lambda^{\mu}(p,\ p')$, (i = 0, 1, 2). (395)
Λ_{ν}^{μ} = Lorentz transformation. (168)
λ = fictitious virtual photon mass used to avoid infrared divergences. (393)
λ_a = number of particle/antiparticle pair types in the calculation of b_n. (314)

M
$\mu^2 = \frac{m^2 c^4}{\hbar^2}$ $\left(= m^2\right.$ in natural units). (42)
$\boldsymbol{\mu} = I\,\boldsymbol{A}$ = magnetic moment due to a current (I) loop enclosing and area (A). (411)
μ_B = Bohr magneton. (411)

Π
$\Pi^{\mu\nu}(k)$ = photon self-energy integral. (323, 379-383, 389-393)
$\Pi_c\left(k^2\right)$ = convergent part of photon self-energy integral. (323, 383)
π_s = conjugate momentum density of field ϕ_s. (4)

P
ρ = density (may be any density. In QM, often probability density). (45, 46)
ρ_{charge} = charge density. (**183**, 422)
$\overline{\rho}_{\nu}$ = vacuum energy density of the zero point energy. (279)

Σ
$\Sigma(p)$ = fermion self-energy integral. (323)
Σ_c(pslash $-$ m) = convergent part of fermion self-energy integral. (323)
$\boldsymbol{\Sigma}$ = RQM spin operator. (93)
$_{\text{QFT}}\,\Sigma_i$ = QFT Dirac spin operator. (114)
$\Sigma_{\mathbf{p}}$ = RQM helicity operator. (100)
Σ_{eig}^{i} = eigenvalue of the Σ_i spin operator. (417)
σ = scattering cross section; “effective” cross section. (432)
$d\sigma$ = cross section for dN_f states. (444)
σ_i = Pauli matrices. (94)
$\sigma^{\mu\nu} = \frac{i}{2}[\gamma^{\mu},\ \gamma^{\nu}]$ = function of the commutator of the γ matrices. (414)
$\frac{d\sigma}{d\Omega}(\theta)$ = differential scattering cross section. (436)

T
τ = proper time. (32)

Φ
Φ = scalar potential. (135)
$\phi(x)$ = plane wave eigensolutions of the Klein-Gordon equation for a scalar particle. (43, **50**)

$\phi_{\mathbf{k}}$ = eigensolution of the Klein-Gordon equation for wave number vector **k**. (44)
ϕ = total scalar particle lowering operator field. (**50**, 60)
ϕ^{+} = scalar particle destruction operator field. (**50**, 60)
ϕ^{-} = scalar antiparticle creation operator field. (**50**, 60)
$\phi^{\dagger}$ = total scalar particle raising operator field. (**50**, 60)
$\phi^{\dagger +}$ = scalar antiparticle destruction operator field. (**50**, 60)
$\phi^{\dagger -}$ = scalar particle creation operator field. (**50**, 60)

Ψ

Ψ = general wave function; solution of the time dependent Schrödinger equation. (45)
ψ = general state solution to Dirac equation; total spinor particle lowering operator field. (103, **111**)
ψ^{+} = spinor particle destruction operator field. (103, **111**)
ψ^{-} = spinor antiparticle creation operator field. (103, **111**)
$\overline{\psi}$ = general state solution to adjoint Dirac equation; total spinor particle raising operator field. (103, **111**)
$\overline{\psi}^{+}$ = spinor antiparticle destruction operator field. (103, **111**)
$\overline{\psi}^{-}$ = spinor particle creation operator field. (103, **111**)
$|\psi^{(n)}\rangle$ = eigensolutions to the Dirac equation (n = 1, 2, 3, 4). (89)
ψ_{state} = discrete plane wave general state solution to the Dirac equation. (91)
$\overline{\psi}_{\text{state}}$ = discrete plane wave general state solution to the adjoint Dirac equation. (91)

Ω

$\omega_{\mathbf{k}}$ ($= E_k$ in natural units) = angular frequency (or energy in natural units) of a wave with wave number vector **k**. (43)
$d\,\Omega = \sin\theta\ d\phi\ d\theta$ = solid angle subtended by the detector in a scattering experiment. (436)