Appendix A
Tables of Fractional Derivatives and q-Derivatives

In this appendix, we collect the Riemann–Liouville fractional derivative and Caputo fractional of some q-analogues of the celebrated special functions and we also include a table of Riemann–Liouville fractional derivative for comparison.

A.1 Table of Riemann–Liouville Fractional Derivatives

Table A.1 Riemann–Liouville fractional derivatives

$\phi(x)$	$\left(D_{0+}^{\alpha}\phi\right)(x),\ x>0,\ \alpha>0$
$x^{\beta-1}$	$\dfrac{\Gamma(\beta)}{\Gamma(\beta-\alpha)}x^{\beta-\alpha-1},\ \beta>0$
$e^{\lambda x}$	$(x)^{-\alpha}E_{1,1-\alpha}(\lambda x)$
$x^{\beta-1}e^{\lambda x}$	$\dfrac{\Gamma(\beta)}{\Gamma(\beta-\alpha)}x^{\beta-\alpha-1}\,{}_1F_1(\beta;\beta-\alpha;\lambda x)$
$\cos(\lambda x)$	$x^{-\alpha}E_{1/2,1-\alpha}(-\lambda^2x^2)$
$\sin(\lambda(x-a))$	$x^{1-\alpha}\lambda E_{1/2,2-\alpha}(-\lambda^2x^2)$
$x^{\beta-1}E_{\mu,\beta}(\lambda x^{\mu})$	$x^{\beta-\alpha-1}E_{\mu,\beta-\alpha}(\lambda x^{\mu}),\ \beta,\ \mu>0$
$x^{\beta-1}\,{}_2F_1\left(\mu,\nu;\beta;\lambda x\right)$	$\dfrac{\Gamma(\beta)}{\Gamma(\beta-\alpha)}x^{\beta-\alpha+1}\,{}_2F_1\left(\mu,\nu;\beta-\alpha;\lambda x\right),\ \beta>0$

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A.2 Table of Riemann–Liouville Fractional q-Derivatives

Table A.2 Riemann–Liouville fractional q-derivatives

ϕ	$D_q^\alpha \phi \quad x > 0, \quad \alpha > 0$
$x^{\beta-1},\ \beta > 0$	$x^{\beta-\alpha-1}\frac{\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}$
$e_q(\lambda x)$	$x^{-\alpha}e_{1,1-\alpha}(\lambda x(1-q)^{-1};q)$
$E_q(\lambda x)$	$x^{-\alpha}E_{1,1-\alpha}(\lambda x(1-q)^{-1};q)$
$x^{\beta-1}e_q(\lambda x)$	$\frac{x^{\beta-\alpha-1}\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}{}_2\phi_1(0,q^\beta;q^{\beta-\alpha},q,\lambda x),\ \beta > 0$
$x^{\beta-1}E_q(\lambda x)$	$\frac{x^{\beta-\alpha-1}\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}{}_1\phi_1(q^\beta;q^{\beta-\alpha};q,\lambda x),\ \beta > 0$
$\cos_q \lambda x$	$x^{-\alpha}e_{2,1-\alpha}(-\lambda^2x^2(1-q)^{-2};q)$
$\sin_q \lambda x$	$\lambda(1-q)^{-1}x^{1-\alpha}e_{2,2-\alpha}(-\lambda^2x^2(1-q)^{-2};q)$
$\mathrm{Cos}_q\lambda x$	$\frac{x^{-\alpha}}{\Gamma_q(1-\alpha)}{}_1\phi_2(q^2;q^{2-\alpha},q^{1-\alpha};q^2,-q\lambda^2x^2)$
$\mathrm{Sin}_q\lambda x$	$\frac{\lambda x^{1-\alpha}}{\Gamma_q(1-\alpha)}{}_1\phi_2(q^2;q^{2-\alpha},q^{1-\alpha};q^2,-q^3\lambda^2x^2)$
$\cos(\lambda x;q)$	$x^{-\alpha}E_{2,1-\alpha}(-q\lambda^2x^2;q)$
$\sin(\lambda x;q)$	$\lambda x^{1-\alpha}E_{2,2-\alpha}(-q^2\lambda^2x^2;q)$
$x^{\beta-1}E_{\mu,\beta}(\lambda x^\mu;q)$	$x^{\beta-\alpha-1}E_{\mu,\beta-\alpha}(\lambda x^\mu;q),\ \beta,\ \mu > 0$
$x^{\beta-1}e_{\mu,\beta}(\lambda x^\mu;q)$	$x^{\beta-\alpha-1}e_{\mu,\beta-\alpha}(\lambda x^\mu;q),\ \beta,\mu > 0$
$x^{\beta-1}\,{}_2\phi_1\left(a,b;q^\beta;q,\lambda x\right)$	$\dfrac{\Gamma_q(\beta)x^{\beta-\alpha-1}}{\Gamma_q(\beta-\alpha)}\,{}_2\phi_1\left(a,b;q^{\beta-\alpha};q,\lambda x\right),\ \beta > 0$
$x^{\beta-1}\,{}_2\phi_1\left(a,b;c;q,\lambda x\right)$	$\dfrac{\Gamma_q(\beta)x^{\beta-\alpha-1}}{\Gamma_q(\beta-\alpha)}\,{}_3\phi_2\left(a,b,q^\beta;c,q^{\beta-\alpha};q,\lambda x\right),\ \beta > 0$

A.3 Table of the Erdéli–Kober Fractional q-Integral Operator

The next table contains the Erdéli–Kober fractional integrals for some q-functions. An extended table can be found in [271].

Table A.3 The integral operator $I_q^{\eta,\alpha}$

ϕ	$I_q^{\eta,\alpha}\phi \quad (x>0)$
$x^{\beta-1}$	$x^{\beta-1}\dfrac{\Gamma_q(\eta+\beta)}{\Gamma_q(\eta+\beta+\alpha)}$, Re $(\beta+\eta)>0$
$x^{\beta-1}e_q(\lambda x)$, Re $(\beta+\eta)>0$	$x^{\beta-1}\dfrac{\Gamma_q(\eta+\beta)}{\Gamma_q(\eta+\beta+\alpha)}{}_2\phi_1\left(0,q^{\eta+\beta};q^{\eta+\beta+\alpha};q,\lambda x\right)$
$x^{\beta-1}E_q(\lambda x)$, Re $(\beta+\eta)>0$	$x^{\beta-1}\dfrac{\Gamma_q(\eta+\beta)}{\Gamma_q(\eta+\beta+\alpha)}{}_1\phi_1\left(q^{\eta+\beta};q^{\eta+\alpha+\beta};q,-\lambda x\right)$
$x^{\beta-1}\cos_q\lambda x$, Re $(\beta+\eta)>0$	$x^{\beta-1}\dfrac{\Gamma_q(\eta+\beta)}{\Gamma_q(\eta+\beta+\alpha)}\times$ ${}_4\phi_3(0,0,q^{\eta+\beta},q^{\eta+\beta+1};q^{\beta+\alpha+\eta},q^{\beta+\alpha+\eta+1};q^2,-\lambda^2x^2)$
$x^{\beta-1}\operatorname{Cos}_q(\lambda x)$, Re $(\beta+\eta)>0$	$\dfrac{x^{\beta-1}\Gamma_q(\eta+\beta)}{\Gamma_q(\eta+\beta+\alpha)}\times$ ${}_2\phi_3(q^{\eta+\beta},q^{\eta+\beta+1};q,q^{\eta+\alpha+\beta},q^{\eta+\alpha+\beta+1};q^2,-q\lambda^2x^2)$,
$x^{\beta-1}\cos(\lambda x;q)$, Re $(\beta+\eta)>0$	$x^{\beta-1}\dfrac{\Gamma_q(\beta+\eta)}{\Gamma_q(\beta+\eta+\alpha)}\times$ ${}_3\phi_3\left(0,q^{\beta+\eta},q^{\beta+\eta+1};q,q^{\beta+\eta+\alpha},q^{\beta+\eta+\alpha+1};q^2,q\lambda^2(1-q)^2x^2\right)$
$x^{\beta-1}\sin_q\lambda x$, Re$(\beta+\eta)>-1$	$\dfrac{\lambda x^\beta\Gamma_q(\eta+\beta+1)}{(1-q)\Gamma_q(\eta+\beta+\alpha+1)}\times$ ${}_4\phi_3\left(0,0,q^{\eta+\beta+1},q^{\eta+\beta+2};q^3,q^{\eta+\beta+\alpha+1},q^{\eta+\beta+\alpha+2};q^2,-\lambda^2x^2\right)$
$x^{\beta-1}\operatorname{Sin}_q\lambda x$, Re$(\beta+\eta)>-1$	$\dfrac{x^\beta\lambda\Gamma_q(\eta+\beta+1)}{(1-q)\Gamma_q(\eta+\beta+\alpha+1)}\times$ ${}_2\phi_3\left(q^{\eta+\beta+1};q^{\eta+\beta+2};q^3,q^{\eta+\beta+1+\alpha},q^{\eta+\beta+\alpha+2};q^2,-q^3\lambda^2x^2\right)$
$x^{\beta-1}\sin(\lambda x;q)$ Re$(\beta+\eta)>-1$	$\lambda x^\beta\dfrac{\Gamma_q(\beta+\eta+1)}{\Gamma_q(\beta+\eta+\alpha+1)}\times$ ${}_3\phi_3\left(0,q^{\beta+\eta+1},q^{\beta+\eta+2};q^3,q^{\beta+\eta+\alpha+1},q^{\beta+\eta+\alpha+2};q^2,\right.$ $\left.q^2\lambda^2(1-q)^2x^2\right)$
$x^{\beta-1}E_{\mu,\beta+\eta}(\lambda x^\mu;q)$, Re$(\beta+\eta)>0$	$x^{\beta-1}E_{\mu,\beta+\eta+\alpha}(\lambda x^\mu;q)$, Re$(\mu)>0$
$x^{\beta-1}e_{\mu,\beta+\eta}(\lambda x^\mu;q)$ Re$(\beta+\eta)>0$	$x^{\beta-1}e_{\mu,\beta+\eta+\alpha}(\lambda x^\mu;q)$, Re$(\mu)>0$
$x^{\beta-1}{}_2\phi_1(a,b;c;q,\lambda x)$, Re$(\beta+\eta)>0$	$x^{\beta-1}\dfrac{\Gamma_q(\beta+\eta)}{\Gamma_q(\beta+\eta+\alpha)}{}_3\phi_2\left(a,b,q^{\beta+\eta};c,q^{\beta+\eta+\alpha};q,\lambda x\right)$

A.4 Table of Erdéli–Sneddon q-Fractional Integral Operator

Most of the results in the following table are proved in [19].

Table A.4 The integral operator $K_q^{\eta,\alpha}$

$\phi(x)$	$K_q^{\eta,\alpha}\phi(x)$
$x^\lambda,\ \operatorname{Re}\eta > \operatorname{Re}\lambda$	$q^{-\alpha\lambda}\dfrac{\Gamma_q(\eta-\lambda)}{\Gamma_q(\eta-\lambda+\alpha)}x^\lambda$
$x^{\eta+\alpha+\lambda}\,(b/x;q)_\lambda\,,\ \operatorname{Re}(\alpha+\lambda)<0$	$\dfrac{\Gamma_q(-\alpha-\lambda)}{\Gamma_q(-\lambda)}q^{-\alpha(\eta+\lambda+\alpha)}x^{\eta+\alpha+\lambda}(b/x;q)_{\lambda+\alpha}$
$x^{-\lambda+\eta}e_q(c/x),\ \operatorname{Re}\eta > \operatorname{Re}\lambda$	$x^{\eta-\lambda}q^{\alpha(\lambda-\eta)}\dfrac{\Gamma_q(\lambda)}{\Gamma_q(\lambda+\alpha)}{}_2\phi_1$ $\left(0,q^\lambda;q^{\lambda+\alpha};q,cq^\alpha/x\right),\ \lvert\frac{cq^\alpha}{x}\rvert<1$
$x^{\eta+\alpha}e_q(x)$	$x^{\eta+\alpha}q^{-\alpha(\eta+\alpha)}(1-q)^\alpha e_q(xq^{-\alpha})(q/x;q)_\alpha$
$x^{\mu+\eta-1}(ax;q)_\nu,\ \operatorname{Re}(\nu+\mu)<1$	$x^{\mu+\eta-1}q^{-\alpha(\mu+\eta-1)}(1-q)^\alpha(axq^{-\alpha};q)_\nu\times$ ${}_2\phi_1\left(q^\alpha,q^{\alpha+1}/ax;q^{\alpha+1-\nu}/ax;q;q^{-\mu-\nu+1}\right),$ $\lvert x\rvert<1$
$x^{\lambda+\eta-1}{}_2\phi_1\,(a,b;c;q,1/x)\,,$ $\lvert x\rvert > \min(1,\operatorname{Re}(\alpha)),\ \operatorname{Re}\lambda<1$	$q^{-\alpha(\lambda+\eta-1)}\dfrac{\Gamma_q(1-\lambda)}{\Gamma_q(1-\lambda+\alpha)}\times$ ${}_3\phi_2\left(a,b,q^{1-\lambda};c,q^{1-\lambda+\alpha};q,q^\alpha/x\right)$

A.5 Table of Caputo Fractional q-Derivatives

Table A.5 Caputo fractional q-derivative

ϕ	${}^cD_q^\alpha\phi\quad x>0,\quad \alpha>0,\lceil\alpha\rceil=n,\beta>n,\ \mu>0$
$x^{\beta-1},\ \ \beta\notin\mathbb{N}$	$x^{\beta-\alpha-1}\frac{\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}$
$x^{\beta-1}$	$zero$ if $\beta\in\{1,2,\ldots,n-1\}$
$e_q(\lambda x)$	$\lambda^n(1-q)^{-n}x^{n-\alpha}e_{1,n+1-\alpha}(\lambda x(1-q)^{-1};q)$
$E_q(\lambda x)$	$\lambda^n(1-q)^{-n}x^{n-\alpha}E_{1,n+1-\alpha}(q^n\lambda x(1-q)^{-1};q)$
$x^{\beta-1}e_q(\lambda x),\ \beta\notin\mathbb{N}$	$\dfrac{\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}x^{\beta-\alpha-1}{}_2\phi_1(0,q^\beta;q^{\beta-\alpha};q,\lambda x)$

(continued)

Table A.5 (continued)

$x^{\beta-1}E_q(\lambda x),\ \beta\notin\mathbb{N}$	$\dfrac{\Gamma_q(\beta)}{\Gamma_q(\beta-\alpha)}x^{\beta-\alpha-1}{}_1\phi_1(q^\beta;q^{\beta-\alpha};q,\lambda x)$
$\cos_q\lambda x$	$\left(\frac{-\lambda^2x^2}{(1-q)^2}\right)^{\lceil n/2\rceil}x^{-\alpha}e_{2,2\lceil n/2\rceil-\alpha+1}(-\lambda^2x^2(1-q)^{-2};q)$
$\sin_q\lambda x$	$(-1)^{[n/2]}x^{-\alpha}\left(\frac{\lambda x}{1-q}\right)^{2[n/2]+1}e_{2,2+2[n/2]-\alpha}$ $(-\lambda^2x^2(1-q)^{-2};q)$
$\mathrm{Cos}_q\lambda x$	$\left(\frac{-\lambda^2x^2}{(1-q)^2}\right)^{\lceil n/2\rceil}x^{-\alpha}\dfrac{q^{\lceil n/2\rceil(2\lceil n/2\rceil-1)}}{\Gamma_q(2\lceil n/2\rceil-\alpha)}\times$ ${}_1\phi_2(q^2;q^{2\lceil n/2\rceil-\alpha+1},q^{\lceil n/2\rceil-\alpha+2};q^2,-q^{4\lceil n/2\rceil+1}\lambda^2x^2)$
$\mathrm{Sin}_q\lambda x$	$\left(\frac{\lambda x}{1-q}\right)^{2[n/2]+1}x^{-\alpha}\dfrac{(-q^{2[n/2]+1})^{[n/2]}}{\Gamma_q\,(1-\alpha+2[n/2])}\times$ ${}_1\phi_2(q^2;q^{2[n/2]-\alpha+2},q^{2[n/2]-\alpha+3};q^2,-q^{3+4[n/2]}\lambda^2x^2)$
$\cos(\lambda x;q)$	$\left(-q^{\lceil n/2\rceil}\lambda^2x^2\right)^{\lceil n/2\rceil}x^{-\alpha}\times$ $E_{2,2\lceil n/2\rceil-\alpha+1}(-q^{\lceil n/2\rceil+2}\lambda^2x^2;q)$
$\sin(\lambda x;q)$	$(-1)^{[n/2]}q^{[n/2]([n/2]+1)}(\lambda x)^{1+2[n/2]}x^{-\alpha}\times$ $E_{2,2[n/2]-\alpha+2}\,(-q^{1+2[n/2]}\lambda^2x^2;q)$
$x^{\beta-1}E_{\mu,\beta}(\lambda x^\mu;q),\ \beta\notin\mathbb{N}$	$x^{\beta-\alpha-1}E_{\mu,\beta-\alpha}(\lambda x^\mu;q)$
$x^{\beta-1}e_{\mu,\beta}(\lambda x^\mu;q),\ \beta\notin\mathbb{N}$	$x^{\beta-\alpha-1}e_{\mu,\beta-\alpha}(\lambda x^\mu;q)$
${}_2\phi_1\,(a,b;c;q,\lambda x)$	$\dfrac{\lambda^nx^{n-\alpha}(a,b;q)_n}{(c;q)_n\Gamma_q(1-\alpha+n)}\times$ ${}_3\phi_2\left(aq^n,bq^n,q;cq^n,q^{1-\alpha+n};q,\lambda x\right)$

A.6 The ±1/2 Riemann–Liouville Fractional q-Derivatives

It is known that in fractional calculus, the Riemann–Liouville fractional derivative of order $1/2$ is very suitable for describing some physicals phenomena. Therefore, we collect here the Riemann–Liouville fractional q-derivative and fractional q-integral of order $1/2$ of some q-functions.

Table A.6 The $\pm 1/2$ Riemann–Liouville fractional derivatives

$f(x)$	$D_q^{1/2} f(x)$	$I_q^{1/2} f(x)$
$e_q(x(1-q))$	$\frac{1}{\sqrt{x}\Gamma_q(1/2)} +$ $e_q(x(1-q))\,\mathrm{Erf}(\sqrt{x};\sqrt{q})$	$e_q(x(1-q))\,\mathrm{Erf}(\sqrt{x};\sqrt{q})$
$e_q(x(1-q))\,\mathrm{Erf}(\sqrt{x};\sqrt{q})$	$e_q(x(1-q))$	$\left(e_q(x(1-q))-1\right)$
$E_q(xq^{-1/2}(1-q))$	$\frac{1}{\sqrt{x}\Gamma_q(1/2)} +$ $\frac{E_q(x(1-q))\,\mathrm{erf}(\sqrt{x};\sqrt{q})}{\sqrt{q}K_q(1/2)}$	$\frac{1}{K_q(1/2)} E_q(x(1-q))\,\mathrm{erf}(\sqrt{x};\sqrt{q})$
$E_q(x(1-q))\,\mathrm{erf}(\sqrt{x};\sqrt{q})$	$q^{-1/4}\mathrm{e}_q(q^{1/2}x(1-q))$	$\sqrt{q}K_q(1/2)\left(E_q(x(1-q)/\sqrt{q})-1\right)$
$J_0^{(1)}(2\sqrt{z};q)$	$\frac{1}{\Gamma_q(1/2)\sqrt{z}}\cos_{\sqrt{q}}(\sqrt{z})$	$\frac{(1-q)}{\Gamma_q(1/2)}\sin_{\sqrt{q}}(\sqrt{z})$
$J_0^{(2)}(2\sqrt{z};q)$	$\frac{1}{\Gamma_q(1/2)\sqrt{z}}\mathrm{Cos}_{\sqrt{q}}(q\sqrt{z})$	$\frac{q^{1/4}(1-q)}{\Gamma_q(1/2)}\mathrm{Sin}_{\sqrt{q}}(\sqrt{z}/\sqrt{q})$
$J_0^{(3)}(\sqrt{z};q)$	$\frac{1}{\Gamma_q(1/2)\sqrt{z}}\mathrm{Cos}(\sqrt{z/1-q};q)$ or $\frac{1}{\Gamma_q(1/2)\sqrt{z}}$ $\times\cos(\sqrt{z\sqrt{q}/1-q};\sqrt{q})$	$\frac{(1-q)}{\Gamma_q(1/2)}\mathrm{Sin}(\sqrt{z/1-q};q)$ or $\frac{(1-q)}{\Gamma_q(1/2)}\sin(\sqrt{z/1-q};\sqrt{q})$

A.7 Generalized Rodrigues q-Type Formulae

The results mentioned in the table below are q-analogues of the results introduced by Lavoie, Osler, and Tremblay in [178]. The derivations of these formulas follow by applying Theorem 4.26. In some times we use some transformation. For example in deriving the Rodrigues formula of ${}_2\phi_1(q^a,q^b;q^c;z)$ we use Heine's transformation of q-series, cf. [113, Eq. (III.1)]. All the functions in the table are defined in the book except the little Legendre function which is defined by

$$P_\nu(x|q) = {}_2\phi_1\left(q^{-\nu}, q^{\nu+1}; q; q, qx\right),$$

where ν is a nonnegative integer, it is called little Legendre polynomial. See [252, Eq. (1.26)].

Table A.7 Generalized Rodrigues type formulae

First Jackson q-Bessel	$J_\nu^{(1)}(2\sqrt{x};q^2) = \dfrac{(1-q^2)^{-\nu+1}}{\Gamma_{q^2}(1/2)} x^{-\nu/2} D_{q^2}^{-\nu+1/2} \sin_q(\sqrt{x})$
Second Jackson q-Bessel	$J_\nu^{(2)}(2\sqrt{x};q) = q^{\frac{1-2\nu}{4}} \dfrac{(1-q^2)^{-\nu+1}}{\Gamma_{q^2}(1/2)} x^{-\nu/2} D_{q^2}^{-\nu+1/2} \mathrm{Sin}_q(q^{\frac{2\nu-1}{4}}\sqrt{x})$
Third Jackson q-Bessel	$J_\nu^{(3)}(\sqrt{x};q) = \dfrac{(1-q^2)^{-\nu+1}}{\Gamma_{q^2}(1/2)} x^{-\nu/2} D_q^{-\nu+1/2} \sin(x/1-q;q)$
Little Legendre function	$P_\nu(x\|q) = \dfrac{1}{\Gamma_q(\nu+1)} D_q^\nu \left(x^\nu (q^{-\nu+1}x;q)_\nu\right)$
Little incomplete q-gamma	$\gamma_q(a,x) = \Gamma_q(a) e_q(-x(1-q)) D_q^{-a} E_q(q^a x(1-q)$
Big incomplete q-gamma	$\Gamma_q(a,x) = \Gamma_q(a) E_q(q^{-1}x(1-q)) D_a^{-a} e_q(q^{-1}x(1-q))$
${}_2\phi_1(q^a,q^b;q^c;x),\ \|x\|<1$	$\dfrac{\Gamma_q(c)}{\Gamma_q(b)} x^{1-c} D_q^{b-c} \left(x^{b-1}(x;q)_{-a}\right)$
${}_1\phi_1(q^a;q^c;q,x),\ x \in \mathbb{C}$	$\dfrac{\Gamma_q(c)}{\Gamma_q(a)} x^{1-c} D_q^{a-c} \left(x^{a-1}(x;q)_\infty\right)$

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