

Advanced Engineering Mathematics Complex Analysis by Dennis G. Zill Problems

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February 2023

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17 Functions of a Complex Variable

17.1 Complex Numbers

17.1.1

$$3 + 3i$$

17.1.3

$$i^8 = (i^2)^4 = (-1)^4 = 1$$

17.1.5

$$7 - 13i$$

17.1.7

$$-7 + 5i$$

17.1.9

$$11 - 10i$$

17.1.11

$$-5 + 12i$$

17.1.13

$$-2i$$

17.1.15

$$\begin{aligned}\frac{2-4i}{3+5i} &= \frac{(2-4i)(3-5i)}{34} \\ &= \frac{-14-22i}{34} \\ &= -\frac{7}{17} - \frac{11}{17}i\end{aligned}$$

17.1.17

$$\begin{aligned}\frac{(3-i)(2+3i)}{1+i} &= \frac{9+7i}{1+i} \\ &= \frac{(9+7i)(1-i)}{2} \\ &= \frac{16-2i}{2} \\ &= 8-i\end{aligned}$$

17.1.27

$$\begin{aligned}\frac{1}{z} &= \frac{\bar{z}}{z\bar{z}} \\ &= \frac{x-iy}{x^2+y^2} \\ \operatorname{Re}\left(\frac{1}{z}\right) &= \frac{x}{x^2+y^2}\end{aligned}$$

17.1.29

$$\begin{aligned}2z + 4\bar{z} - 4i &= 2(x + iy) + 4(x - iy) - 4i \\&= 6x - 2(y + 2)i \\ \operatorname{Im}(2z + 4\bar{z} - 4i) &= -2y - 4\end{aligned}$$

17.1.31

$$\begin{aligned}z - 1 - 3i &= x + iy - 1 - 3i \\&= (x - 1) + (y - 3)i \\ |z| &= \sqrt{(x - 1)^2 + (y - 3)^2}\end{aligned}$$

17.1.33

$$\begin{aligned}2z &= i(2 + 9i) \\&= -9 + 2i \\ z &= -\frac{9}{2} + i\end{aligned}$$

17.1.35

$$\begin{aligned}(x + iy)^2 &= x^2 + 2xyi - y^2 \\&= (x^2 - y^2) + 2xyi \\ x^2 &= y^2 \\ x &= y \\ 2xy &= 1 \\ x^2 &= \frac{1}{2} \\ x &= \frac{\sqrt{2}}{2} \\ z &= \frac{\sqrt{2}}{2}(1 + i)\end{aligned}$$

17.1.37

$$\begin{aligned}
z + 2\bar{z} &= x + iy + 2x - 2iy \\
&= 3x - iy \\
\frac{2-i}{1+3i} &= \frac{(2-i)(1-3i)}{10} \\
&= \frac{-1-7i}{10} \\
3x - iy &= \frac{-1-7i}{10} \\
x &= -\frac{1}{30} \\
y &= \frac{7}{10} \\
z &= -\frac{1}{30} + \frac{7}{10}i
\end{aligned}$$

17.1.39

$$\begin{aligned}
|10 + 8i| &\approx 12.8 \\
|11 - 6i| &\approx 12.5
\end{aligned}$$

$11 - 6i$ is closer.

17.2 Powers and Roots**17.2.1**

$$2(\cos 0 + i \sin 0)$$

17.2.3

$$-3[\cos(-\pi/2) + i \sin(-\pi/2)]$$

17.2.5

$$\sqrt{2}[\cos(\pi/4) + i \sin(\pi/4)]$$

17.2.7

$$2[\cos(5\pi/6) + i \sin(5\pi/6)]$$

17.2.9

$$\begin{aligned}\frac{3}{-1+i} &= \frac{3(-1-i)}{2} \\ &= \frac{-3-3i}{2} \\ &= -\frac{3}{2} - \frac{3}{2}i \\ &= \frac{3\sqrt{2}}{2}[\cos(5\pi/4) + i\sin(5\pi/4)]\end{aligned}$$

17.2.11

$$-\frac{5\sqrt{3}}{2} - \frac{5}{2}i$$

17.2.13

$$5.54 + 2.30i$$

17.2.15

$$\begin{aligned}8[\cos(\pi/2) + i\sin(\pi/2)] &= 8i \\ \frac{1}{2}[\cos(-\pi/4) + i\sin(-\pi/4)] &= \frac{\sqrt{2}}{4} - \frac{\sqrt{2}}{4}i\end{aligned}$$

17.2.21

$$\begin{aligned}(1 + \sqrt{3}i)^9 &= \{2[\cos(\pi/3) + i\sin(\pi/3)]\}^9 \\ &= 512(\cos \pi + i\sin \pi) \\ &= -512\end{aligned}$$

17.2.23

$$\begin{aligned}\left(\frac{1}{2} + \frac{1}{2}i\right)^{10} &= \left\{\frac{\sqrt{2}}{2}[\cos(\pi/4) + i\sin(\pi/4)]\right\}^{10} \\ &= \frac{1}{32}[\cos(\pi/2) + i\sin(\pi/2)] \\ &= \frac{1}{32}i\end{aligned}$$

17.2.27

$$w_k = 2[\cos(2\pi k/3) + i \sin(2\pi k/3)]$$

$$w_0 = 2$$

$$w_1 = -1 + \sqrt{3}i$$

$$w_2 = -1 - \sqrt{3}i$$

17.2.29

$$w_k = \cos(\pi/4 + k\pi) + i \sin(\pi/4 + k\pi)$$

$$w_0 = \frac{\sqrt{2}}{2}(1 + i)$$

$$w_1 = -\frac{\sqrt{2}}{2}(1 + i)$$

17.2.31

$$w_k = \sqrt{2}[\cos(\pi/3 + k\pi) + i \sin(\pi/3 + k\pi)]$$

$$w_0 = \frac{\sqrt{2}}{2} + \frac{\sqrt{6}}{2}i$$

$$w_1 = -\frac{\sqrt{2}}{2} - \frac{\sqrt{6}}{2}i$$

17.2.33

$$z^4 + 1 = 0$$

$$z^4 = -1$$

$$w_k = \cos(\pi/4 + k\pi/2) + i \sin(\pi/4 + k\pi/2)$$

$$w_0 = \frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{2}i$$

$$w_1 = -\frac{\sqrt{2}}{2} + \frac{\sqrt{2}}{2}i$$

$$w_2 = -\frac{\sqrt{2}}{2} - \frac{\sqrt{2}}{2}i$$

$$w_3 = \frac{\sqrt{2}}{2} - \frac{\sqrt{2}}{2}i$$

17.3 Sets in the Complex Plane**17.3.1**

A vertical line at $\operatorname{Re}(z) = 5$.

17.3.3

A horizontal line at $\text{Im}(z) = -3$.

17.3.5

A circle of radius 2 centred at $3i$.

17.3.7

A circle of radius 5 centred at $4 - 3i$.

17.3.9

The region of the plane to the left of (but not including) $\text{Re}(z) = -1$. It is a domain.

17.3.11

The region of the plane above (but not including) $\text{Im}(z) = 3$. It is a domain.

17.3.13

The region of the plane between (but not including) $\text{Re}(z) = 3$ and $\text{Re}(z) = 5$. It is a domain.

17.3.15

$$\begin{aligned} z^2 &= (a + ib)^2 \\ &= a^2 - b^2 + 2iab \\ \text{Re}(z^2) &= a^2 - b^2 \\ \text{Re}(z^2) &> 0 \\ a^2 - b^2 &> 0 \\ a^2 &> b^2 \end{aligned}$$

The region between $y = x$ and $y = -x$. Not a domain.

17.3.17

The region between $\theta = 0$ and $\theta = 2\pi/3$. Not a domain.

17.3.19

The region outside a circle of radius 1 centred at i . It is a domain.

17.3.21

The region between the circles of radius 2 and 3 centred at i . It is a domain.

17.3.23

$$y = -x$$

17.3.25

$$\begin{aligned} z^2 + \bar{z}^2 &= (a + ib)^2 + (a - ib)^2 \\ &= a^2 + 2iab - b^2 + a^2 - 2iab - b^2 \\ &= 2(a^2 - b^2) \\ 2(a^2 - b^2) &= 2 \\ a^2 - b^2 &= 1 \\ a^2 &= b^2 + 1 \end{aligned}$$

The hyperbola $x^2 - y^2 = 1$.

17.4 Functions of a Complex Variable**17.4.1**

$$\begin{aligned} f(z) &= z^2 \\ &= (x + iy)^2 \\ &= x^2 - y^2 + 2ixy \\ u(x, y) &= x^2 - y^2 \\ &= x^2 - 4 \\ v(x, y) &= 2xy \\ &= 4x \\ x &= \frac{v}{4} \\ u &= \left(\frac{v}{4}\right)^2 - 4 \\ &= \frac{1}{16}v^2 - 4 \end{aligned}$$

17.4.3

$$\begin{aligned} u &= -y^2 \\ v &= 0 \end{aligned}$$

Line on the left half of the real axis.

17.4.5

$$\begin{aligned}u &= 0 \\v &= 2x^2\end{aligned}$$

Line on the top half of the imaginary axis.

17.4.7

$$f(x) = (6x - 5) + i(6y + 9)$$

17.4.9

$$f(z) = (x^2 - y^2 - 3x) + i(2xy - 3y + 4)$$

17.4.11

$$f(z) = (x^3 - 3xy^2 - 4x) + i(3x^2y - y^3 - 4y)$$

17.4.13

$$f(z) = \left(x + \frac{x}{x^2 + y^2}\right) i \left(y - \frac{y}{x^2 + y^2}\right)$$

17.4.15

(a) $-4 + i$

(b) $3 - 9i$

(c) $1 + 86i$

17.4.17

(a) $14 - 20i$

(b) $-13 + 43i$

(c) $3 - 26i$

17.4.19

$$6 - 5i$$

17.4.21

$$-4i$$

17.4.27

$$f'(z) = 12z^2 - 2(3+i)z - 5$$

17.4.29

$$\begin{aligned} f'(z) &= 2(z^2 - 4z + 8i) + (2z + 1)(2z - 4) \\ &= 2z^2 - 8z + 16i + 4z^2 - 8z + 2z - 4 \\ &= 6z^2 - 14z - 4 + 16i \end{aligned}$$

17.4.31

$$f'(z) = 6z(z^2 - 4i)^2$$

17.4.33

$$\begin{aligned} f'(z) &= \frac{3(2z+i) - 2(3z-4+8i)}{(2z+i)^2} \\ &= \frac{6z+3i-6z+8-16i}{(2z+i)^2} \\ &= \frac{8-13i}{(2z+i)^2} \end{aligned}$$

17.4.35

$$3i$$

17.4.37

$$\pm 2i$$

17.4.41

$$\begin{aligned} \frac{dx}{dt} &= 2x \\ x &= c_1 e^{2t} \\ \frac{dy}{dt} &= 2y \\ y &= c_2 e^{2t} \end{aligned}$$

17.4.43

$$\begin{aligned}f(z) &= \frac{1}{\bar{z}} \\&= \frac{1}{x - iy} \\&= \frac{x + iy}{x^2 + y^2} \\&= \frac{x}{x^2 + y^2} + i \frac{y}{x^2 + y^2} \\ \frac{dx}{dt} &= \frac{x}{x^2 + y^2} \\ \frac{dy}{dt} &= \frac{y}{x^2 + y^2} \\ \frac{dy}{dx} &= \frac{y}{x} \\ \frac{dy}{y} &= \frac{dx}{x} \\ \ln y &= \ln x + c_1 \\ y &= c_2 x\end{aligned}$$

17.5 Cauchy-Riemann Equations

17.5.1

$$\begin{aligned}f(z) &= z^3 \\&= (x + iy)^3 \\&= (x^2 + 2ixy - y^2)(x + iy) \\&= x^3 + ix^2y + 2ix^2y - 2xy^2 - xy^2 - iy^3 \\&= (x^3 - 3xy^2) + i(3x^2y - y^3) \\ \frac{\partial u}{\partial x} &= 3x^2 - 3y^2 \\&= \frac{\partial v}{\partial y} \\ \frac{\partial u}{\partial y} &= -6xy \\&= -\frac{\partial v}{\partial x}\end{aligned}$$

17.5.3

$$\begin{aligned}
f(z) &= \operatorname{Re}(z) \\
&= x \\
\frac{\partial u}{\partial x} &= 1 \\
&\neq \frac{\partial v}{\partial y}
\end{aligned}$$

17.5.5

$$\begin{aligned}
f(z) &= 4z - 6\bar{z} + 3 \\
&= 4(x + iy) - 6(x - iy) + 3 \\
&= (-2x + 3) + 10iy \\
\frac{\partial u}{\partial x} &= -2 \\
&\neq \frac{\partial v}{\partial y}
\end{aligned}$$

17.5.7

$$\begin{aligned}
f(z) &= x^2 + y^2 \\
\frac{\partial u}{\partial x} &= 2x \\
&\neq \frac{\partial v}{\partial y}
\end{aligned}$$

17.5.9

$$\begin{aligned}
f(z) &= e^x \cos y + ie^x \sin y \\
u &= e^x \cos y \\
\frac{\partial u}{\partial x} &= e^x \cos y \\
\frac{\partial u}{\partial y} &= -e^x \sin y \\
v &= e^x \sin y \\
\frac{\partial v}{\partial x} &= e^x \sin y \\
\frac{\partial v}{\partial y} &= e^x \cos y
\end{aligned}$$

Analytic everywhere.

17.5.11

$$f(z) = x + \sin x \cosh y + i(y + \cos x \sinh y)$$

$$u = x + \sin x \cosh y$$

$$\frac{\partial u}{\partial x} = 1 + \cos x \cosh y$$

$$\frac{\partial u}{\partial y} = \sin x \sinh y$$

$$v = y + \cos x \sinh y$$

$$\frac{\partial v}{\partial x} = -\sin x \sinh y$$

$$\frac{\partial v}{\partial y} = 1 + \cos x \cosh y$$

Analytic everywhere.

17.5.15

$$f(z) = 3x - y + 5 + i(ax + by - 3)$$

$$u = 3x - y + 5$$

$$\frac{\partial u}{\partial x} = 3$$

$$\frac{\partial u}{\partial y} = -1$$

$$v = ax + by - 3$$

$$\frac{\partial v}{\partial x} = a$$

$$\frac{\partial v}{\partial y} = b$$

$$a = 1$$

$$b = 3$$

17.5.17

$$f(z) = x^2 + y^2 + 2ixy$$

$$u = x^2 + y^2$$

$$\frac{\partial u}{\partial x} = 2x$$

$$\frac{\partial u}{\partial y} = 2y$$

$$v = 2xy$$

$$\frac{\partial v}{\partial x} = 2y$$

$$\frac{\partial v}{\partial y} = 2x$$

Only differentiable when $y = 0$.

17.5.19

$$f(z) = x^3 + 3xy^2 - x + i(y^3 + 3x^2y - y)$$

$$u = x^3 + 3xy^2 - x$$

$$\frac{\partial u}{\partial x} = 3x^2 + 3y^2 - 1$$

$$\frac{\partial u}{\partial y} = 6xy$$

$$v = y^3 + 3x^2y - y$$

$$\frac{\partial v}{\partial x} = 6xy$$

$$\frac{\partial v}{\partial y} = 3y^2 + 3x^2 - 1$$

Only differentiable when $x = 0$ or $y = 0$.

17.5.21

$$f(z) = e^x \cos y + ie^x \sin y$$

$$\begin{aligned} f'(z) &= \frac{\partial u}{\partial x} + i \frac{\partial v}{\partial x} \\ &= e^x \cos y + ie^x \sin y \end{aligned}$$

17.5.23

$$\begin{aligned}
u &= x \\
\frac{\partial^2 u}{\partial x^2} &= 0 \\
\frac{\partial^2 u}{\partial y^2} &= 0 \\
\frac{\partial v}{\partial y} &= 1 \\
v &= y + h(x) \\
h'(x) &= 0 \\
v &= y + c \\
f(z) &= x + i(y + c)
\end{aligned}$$

17.5.25

$$\begin{aligned}
u &= x^2 - y^2 \\
\frac{\partial^2 u}{\partial x^2} &= 2 \\
\frac{\partial^2 u}{\partial y^2} &= -2 \\
\frac{\partial v}{\partial y} &= 2x \\
v &= 2xy + h(x) \\
2y &= 2y + h'(x) \\
h'(x) &= 0 \\
h(x) &= c \\
v &= 2xy + c \\
f(z) &= (x^2 - y^2) + i(2xy + c)
\end{aligned}$$

17.6 Exponential and Logarithmic Functions**17.6.1**

$$\frac{\sqrt{3}}{2} + \frac{1}{2}i$$

17.6.3

$$e^{-1} \frac{\sqrt{2}}{2} (1 + i)$$

17.6.5

$$-e^{\pi}$$

17.6.7

$$e^{1.5}(\cos 2 + i \sin 2) = -1.865 + 4.075i$$

17.6.9

$$\cos 5 + i \sin 5 = 0.2836 - 0.9589i$$

17.6.11

$$\begin{aligned} e^{1+5\pi i/4} e^{-1-\pi i/3} &= e^{11\pi i/12} \\ &= \cos \frac{11\pi}{12} + i \sin \frac{11\pi}{12} \\ &= -0.9659 + 0.2588i \end{aligned}$$

17.6.13

$$\begin{aligned} f(z) &= e^{-iz} \\ &= e^{-i(x+iy)} \\ &= e^{y-ix} \\ &= e^y(\cos x - i \sin x) \end{aligned}$$

17.6.15

$$\begin{aligned} f(z) &= e^{z^2} \\ &= e^{x^2-y^2+2ixy} \\ &= e^{x^2-y^2}[\cos(2xy) + i \sin(2xy)] \end{aligned}$$

17.6.17

$$\begin{aligned} e^z &= e^{x+iy} \\ &= e^x(\cos y + i \sin y) \\ |e^z| &= \sqrt{e^{2x}[\cos^2 y + \sin^2 y]} \\ &= e^x \end{aligned}$$

17.6.19

$$\begin{aligned}
e^{z+\pi i} &= e^{x+i(y+\pi)} \\
&= e^x [\cos(y+\pi) + i \sin(y+\pi)] \\
&= e^x [-\cos y - i \sin y] \\
&= -e^x (\cos y + i \sin y) \\
e^{z-\pi i} &= e^{x+i(y-\pi)} \\
&= e^x [\cos(y-\pi) + i \sin(y-\pi)] \\
&= e^x (-\cos y - i \sin y) \\
&= -e^x (\cos y + i \sin y)
\end{aligned}$$

17.6.21

$$\begin{aligned}
e^{\bar{z}} &= e^{x-iy} \\
&= e^x (\cos y - i \sin y) \\
u &= e^x \cos y \\
v &= -e^x \sin y \\
\frac{\partial u}{\partial x} &= e^x \cos y \\
&\neq \frac{\partial v}{\partial y}
\end{aligned}$$

17.6.23

$$\log_e 5 + i(\pi + 2n\pi) = 1.6094 + i(\pi + 2n\pi)$$

17.6.25

$$\log_e(2\sqrt{2}) + i\left(\frac{3}{4}\pi + 2n\pi\right) = 1.0397 + i\left(\frac{3}{4}\pi + 2n\pi\right)$$

17.6.27

$$\log_e(2\sqrt{2}) + i\left(\frac{1}{3}\pi + 2n\pi\right) = 1.0397 + i\left(\frac{1}{3}\pi + 2n\pi\right)$$

17.6.29

$$\log_e(6\sqrt{2}) - \frac{\pi}{4}i = 2.1383 - \frac{\pi}{4}i$$

17.6.31

$$\log_e 13 + 2.7468i = 2.5649 + 2.7468i$$

17.6.33

$$5 \left(\log_e 2 + \frac{\pi}{3} i \right) = 3.4657 - \frac{\pi}{3} i$$

17.6.35

$$z = \log_e 4 + i \left(\frac{\pi}{2} + 2n\pi \right) = 1.3863 + i \left(\frac{\pi}{2} + 2n\pi \right)$$

17.6.37

$$\begin{aligned} z - 1 &= 2 + i \left(-\frac{\pi}{2} + 2n\pi \right) \\ z &= 3 + i \left(-\frac{\pi}{2} + 2n\pi \right) \end{aligned}$$

17.6.39

$$\begin{aligned} \ln(-i) &= i \left(-\frac{\pi}{2} + 2n\pi \right) \\ (-i)^{4i} &= e^{4i \ln(-i)} \\ &= e^{4i \times i(-\pi/2 + 2n\pi)} \\ &= e^{2\pi(1-4n)} \end{aligned}$$

17.6.41

$$\begin{aligned} \ln(1+i) &= \log_e \sqrt{2} + i \left(\frac{\pi}{4} + 2n\pi \right) \\ (1+i)^{(1+i)} &= e^{(1+i) \ln(1+i)} \\ &= e^{(1+i)[\log_e \sqrt{2} + i(\pi/4 + 2n\pi)]} \\ &= e^{\log_e \sqrt{2} + i(\pi/4 + 2n\pi) + i \log_e \sqrt{2} - (\pi/4 + 2n\pi)} \\ &= e^{(\log_e \sqrt{2} - \pi/4 - 2n\pi) + i(\log_e \sqrt{2} + \pi/4 + 2n\pi)} \\ &= e^{-2n\pi} e^{(\log_e \sqrt{2} - \pi/4) + i(\log_e \sqrt{2} + \pi/4)} \\ &= e^{-2n\pi} e^{\log_e \sqrt{2} - \pi/4} e^{i(\log_e \sqrt{2} + \pi/4)} \\ &= e^{-2n\pi} (0.2739 + 0.5837i) \end{aligned}$$

17.6.43

$$\begin{aligned} \operatorname{Ln}(-1) &= \pi i \\ (-1)^{(-2i/\pi)} &= e^{(-2i/\pi) \operatorname{Ln}(-1)} \\ &= e^{(-2i/\pi)(\pi i)} \\ &= e^2 \end{aligned}$$

17.6.47

(a)

$$\begin{aligned}
(-1+i)^2 &= -2i \\
\operatorname{Ln}(-1+i)^2 &= \operatorname{Ln}(-2i) \\
&= \log_e 2 - \frac{\pi}{2}i \\
2\operatorname{Ln}(-1+i) &= 2\log_e \sqrt{2} + \frac{3\pi}{2}i \\
&\neq \operatorname{Ln}(-1+i)^2
\end{aligned}$$

Not true

(b)

$$\begin{aligned}
\operatorname{Ln} i^3 &= \operatorname{Ln}(-i) \\
&= -\frac{\pi}{2}i \\
3\operatorname{Ln} i &= \frac{3\pi}{2}i \\
&\neq \operatorname{Ln} i^3
\end{aligned}$$

Not true

(c)

$$\begin{aligned}
\ln i^3 &= i \left(-\frac{\pi}{2} + 2n\pi \right) \\
3\ln i &= 3i \left(\frac{\pi}{2} + 2n\pi \right) \\
&\neq \ln i^3
\end{aligned}$$

Not true