

Chapter 6

Complex Variable Methods

In two dimensions there are elegant methods for solving electrostatics problems which take advantage of the fact that analytic functions in the complex $z = x + iy$ plane are *harmonic*—they are solutions of Laplace’s equation. The use of these techniques is almost an art form, and will only be briefly touched upon in the notes. For further details, I can recommend G. F. Carrier, M. Krook, and C. E. Pearson, *Functions of a Complex Variable*.

6.1 Analytic Functions and the Cauchy-Riemann Equations

Let $f(z)$ be a complex function of the complex variable $z = x + iy$. A complex function $f(z)$ is *analytic* at the point z_0 if its derivative df/dz exists at $z = z_0$ and at each point in some neighborhood of z_0 . The derivative is defined similarly to the derivative of a function of a real variable,

$$f'(z_0) \equiv \left(\frac{df}{dz} \right)_{z=z_0} = \lim_{z \rightarrow z_0} \frac{f(z) - f(z_0)}{z - z_0}. \quad (6.1)$$

Most common functions are differentiable, and therefore analytic; for instance, z^n , e^z , $\ln z$, and so on. However, since the limit in Eq. (6.1) must be the same *for any mode of approach*, differentiability for functions of a complex variable is much more restrictive than for functions of a real variable. For instance, the function $f(z) = zz^* = x^2 + y^2$ is *not* differentiable. To see this, consider the limit

$$\lim_{z \rightarrow z_0} \frac{zz^* - z_0z_0^*}{z - z_0} = \lim_{z \rightarrow z_0} \left(z^* + z_0 \frac{z^* - z_0^*}{z - z_0} \right), \quad (6.2)$$

and let z approach z_0 from a direction making a fixed angle θ with the real axis, so that $z - z_0 = re^{i\theta}$, with $r \rightarrow 0$. Then the limit is

$$\lim_{z \rightarrow z_0} \frac{zz^* - z_0z_0^*}{z - z_0} = z_0^* + z_0 e^{-2i\theta}, \quad (6.3)$$

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