

R Fundamental definitions and results

R20 $(x_1 + yi)(x_2 + yi) = (x_1x_2 - y_1y_2) + i(x_1y_2 + x_2y_1)$
 $|x + yi| = \sqrt{x^2 + y^2}$, $|x + yi| = \sqrt{x^2 + y^2}$, $d(z_1, z_2) = |z_1 - z_2|$

R1 $\frac{1}{1-z} = 1 + z + z^2 + z^3 + \dots$ for $|z| < 1$

R2 $e^z = 1 + \frac{z}{1!} + \frac{z^2}{2!} + \frac{z^3}{3!} + \dots$ for any z

R3 In the neighbourhood of a pole z_0 of order k
 $f(z) = \frac{a_{-k}}{(z-z_0)^k} + \dots + \frac{a_{-1}}{(z-z_0)} + a_0 + a_1(z-z_0) + \dots$
 and $\text{Res}_{z_0} f = a_{-1} = \lim_{z \rightarrow z_0} ((z-z_0)^k f(z))^{(k-1)}$

R4 Complex integral of $f: D \rightarrow \mathbb{C}$ along $\gamma: [a, b] \rightarrow D$ is
 $\int_{\gamma} f(z) dz = \int_a^b f(\gamma(t)) \gamma'(t) dt$

R5 Theorem of Residues. For an open set $D \subset \mathbb{C}$:

$f: D \rightarrow \mathbb{C}$ holomorphic function
 S set of isolated singular points
 γ path homotopic to zero in $D \setminus S$

$$\int_{\gamma} f(z) dz = 2\pi i \sum_{z \in S} n(z, \gamma) \text{Res}_z f$$

R6 Lemma 1. For $\gamma_r: [0, \beta] \rightarrow \mathbb{C}$, $\gamma_r(t) = re^{it}$
 $\lim_{r \rightarrow \infty} z f(z) = 0 \Rightarrow \lim_{r \rightarrow \infty} \int_{\gamma_r} f(z) dz = 0$

R7 Lemma 2 (Jordan). For $\gamma_r: [0, \pi] \rightarrow \mathbb{C}$, $\gamma_r(t) = re^{it}$
 $\lim_{r \rightarrow \infty} f(z) = 0 \Rightarrow \lim_{r \rightarrow \infty} \int_{\gamma_r} f(z) e^{iz} dz = 0$

A Problems

1 $(1-2i)^2 = ?$, $\frac{1-i}{1+i} = ?$, $e^{-2i} = ?$, $d(1+i, 2-i) = ?$,
 $(z \sin z)' = ?$, $(e^z)' = ?$, $\lim_{z \rightarrow \infty} \left(\frac{z}{z^2} + \frac{1}{z} \right) = ?$.

2 Expand in a power series of z the functions
 $f_1(z) = e^{z^2}$, $f_2(z) = ze^{z^2}$, $f_3(z) = \frac{1}{1-z^2}$

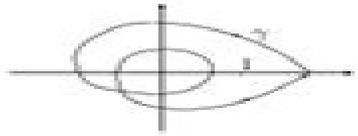
Solution.
 $f_1(z) = 1 + \frac{z^2}{1!} + \frac{z^4}{2!} + \frac{z^6}{3!} + \dots$ for any z .
 $f_2(z) = z \left(1 + \frac{z^2}{1!} + \frac{z^4}{2!} + \frac{z^6}{3!} + \dots \right) = \dots + \frac{z^3}{1!} + \frac{z^5}{2!} + z + \dots$ for $|z| > 0$.
 $f_3(z) = \frac{1}{1-z^2} \left(1 + z + z^2 + z^3 + \dots \right) = \frac{1}{1-z} + \frac{z}{1-z^2} + \dots$ for $0 < |z| < 1$.

3 Compute the residues of $f(z) = \frac{1}{z^3(z-1)^2}$
Hint. 0 is a pole of order 3 and ± 1 are poles of order 2.

B Problems

1 Prove that $f: \mathbb{C} \rightarrow \mathbb{C}$, $f(z) = 1+z$ is not \mathbb{C} -differentiable.
Hint. Use the Cauchy-Riemann theorem.

2 For $\gamma: [0, \pi] \rightarrow \mathbb{C}$, $\gamma(t) = e^{it}$, compute $\int_{\gamma} (z+i) dz$.
Hint. Use the definition of the complex line integral.



3 Compute the integral $\int_{\gamma} \frac{1}{z^2(z-1)} dz$ where γ is the path from the figure above.

Solution. By using the theorem of residues, we get
 $\int_{\gamma} \frac{1}{z^2(z-1)} dz = 2\pi i (2 \text{Res}_0 f + \text{Res}_1 f) = 2\pi i$.

4 Compute the residue of $f(z) = ze^{z^2}$ at the singular point $z_0 = 0$.
Solution. $f(z) = \dots + \frac{z}{1!} + \frac{z^3}{3!} + \dots + 1 + z$ for any $z \Rightarrow \text{Res}_0 f = \frac{1}{2}$.

C Problems

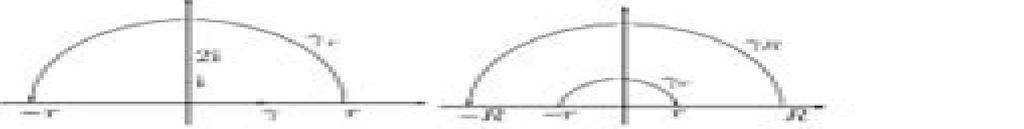
1 Compute the residues of $f(z) = z^2 e^{-z^2}$ at the singular point $z_0 = 1$.
Hint. $f(z) = ((z-1)^2 + 2(z-1) + 1) \left(1 + \frac{1}{2} \frac{z-1}{1} + \frac{1}{2} \frac{(z-1)^2}{1 \cdot 2} + \frac{1}{6} \frac{(z-1)^3}{1 \cdot 2 \cdot 3} + \dots \right)$.

2 Compute the integrals $I_1 = \int_0^{2\pi} \frac{1}{2+e^{it}} dt$ and $I_2 = \int_0^{2\pi} \frac{1}{2+e^{-it}} dt$
Solution. By using the path $\gamma: [0, 2\pi] \rightarrow \mathbb{C}$, $\gamma(t) = e^{it}$, we get
 $I_1 = \int_0^{2\pi} \frac{1}{2+e^{it}} dt = \int_0^{2\pi} \frac{1}{2+e^{it}} e^{it} dt = \int_{\gamma} \frac{1}{2+z} dz = 2\pi \text{Res}_0 f = 2\pi$

$I_2 = \int_0^{2\pi} \frac{1}{2+e^{-it}} dt = \int_0^{2\pi} \frac{1}{2+e^{-it}} e^{-it} dt = \int_{\gamma} \frac{1}{2+z} dz = 2\pi \text{Res}_0 f = 2\pi$

3 Compute the integrals $\int_0^{\infty} \frac{1}{1+e^{2\pi i x}} dx$ and $\int_0^{\infty} \frac{1}{1+e^{2\pi i x + 2\pi i}}$
Solution. The integral is convergent: at infinity $\frac{1}{1+e^{2\pi i x + 2\pi i}} \sim \frac{1}{e^{2\pi i x}}$.
 By using $\gamma_r: [0, \pi] \rightarrow \mathbb{C}$, $\gamma_r(t) = re^{it}$ and $f(z) = \frac{1}{1+e^{2\pi i z}}$, we get
 $\int_{\gamma_r} f(z) dz + \int_{\gamma_r} f(z) dz = 2\pi i (\text{Res}_0 f + \text{Res}_{1/2} f)$, whence
 $\lim_{r \rightarrow \infty} \int_{\gamma_r} f(z) dz + \int_{-\infty}^{\infty} f(x) dx = 2\pi i (\text{Res}_0 f + \text{Res}_{1/2} f)$.

Since $|z f(z)| = \frac{|z|}{|1+e^{2\pi i z}|} = \frac{|z|}{|1-e^{2\pi i z}|} \leq \frac{|z|}{|1-e^{2\pi i}|} = \frac{|z|}{2}$, we have $\lim_{r \rightarrow \infty} \int_{\gamma_r} f(z) dz = 0$ and in view of lemma 1, $\lim_{r \rightarrow \infty} \int_{\gamma_r} f(z) dz = 0$.
 Consequently, $\int_0^{\infty} f(x) dx = \pi i (\text{Res}_0 f + \text{Res}_{1/2} f) = \frac{\pi}{2}$.



4 Prove that $\int_0^{\infty} \frac{\sin x}{x} dx = \frac{\pi}{2}$ (Poisson's integral).

Solution. Let $0 < r < R$ and $\gamma_R, \gamma_r: [0, \pi] \rightarrow \mathbb{C}$, $\gamma_R(t) = Re^{it}$, $\gamma_r(t) = re^{it}$.
 From the residue theorem (right hand side of fig.) it follows the relation
 $\int_{\gamma_R} \frac{e^{iz}}{z} dz + \int_{-\gamma_r} \frac{e^{iz}}{z} dz + \int_{\gamma_r} \frac{e^{iz}}{z} dz + \int_{-\gamma_R} \frac{e^{iz}}{z} dz = 0$, that is
 $\int_{\gamma_R} \frac{e^{iz}}{z} dz + \int_{\gamma_r} \frac{e^{iz}}{z} dz + \int_r^R \frac{e^{ix}}{x} dx + \int_r^R \frac{e^{-ix}}{x} dx = 0$,
 $\int_{\gamma_R} \frac{e^{iz}}{z} dz + \int_{\gamma_r} \frac{1}{z} dz + \int_r^R \frac{e^{ix}-e^{-ix}}{x} dx + 2i \int_r^R \frac{\sin x}{x} dx = 0$.

If g is an antiderivative of $f(z) = \frac{e^{iz}}{z}$, by using $\int_{\gamma_r} \frac{1}{z} dz = -\pi i$, we get
 $\int_{\gamma_R} \frac{e^{iz}}{z} dz - \pi i + (g(R) - g(-R)) + 2i \int_r^R \frac{\sin x}{x} dx = 0$.
 But, in view of Jordan's lemma $\lim_{R \rightarrow \infty} \int_{\gamma_R} \frac{e^{iz}}{z} dz = 0$,
 and for $R \rightarrow \infty$ and $r \rightarrow 0$ we get $2i \int_0^{\infty} \frac{\sin x}{x} dx = \pi i$.

5 Find the holomorphic function $f: \mathbb{C} \rightarrow \mathbb{C}$ with $\frac{\partial f}{\partial x}(x+yi) = 2xy - 2x$, $f(i) = 0$.

6 For $z_0 \neq 0$, expand $f: \mathbb{C}^* \rightarrow \mathbb{C}$, $f(z) = \frac{1}{z}$ in a power series of $(z-z_0)$.
Solution. We have
 $f(z) = \frac{1}{z_0 + (z-z_0)} = \frac{1}{z_0} \frac{1}{1 + \frac{z-z_0}{z_0}} = \frac{1}{z_0} \left(1 - \frac{1}{z_0} (z-z_0) + \frac{1}{z_0^2} (z-z_0)^2 - \dots \right)$,
 for $|z-z_0| < |z_0|$.
 $f(z) = \frac{1}{z_0 + (z-z_0)} = \frac{1}{z_0} \frac{1}{1 - \frac{z-z_0}{z_0}} = \frac{1}{z_0} \left(1 + \frac{1}{z_0} (z-z_0) + \frac{1}{z_0^2} (z-z_0)^2 + \dots \right)$,
 for $|z-z_0| > |z_0|$.

7 Expand in a power series of $(z-i)$ the functions:
 $f_1(z) = \frac{1}{z}$, $f_2(z) = \frac{1}{z^2}$, $f_3(z) = \frac{1}{z} + \frac{1}{z^2}$.

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Robert R. Redfield



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