COMPLEX ANALYSIS - Problems

Nicolae Cotfas, version 29 May 2020 (for future updates see   https://unibuc.ro/user/nicolae.cotfas/)

R **Fundamental definitions and results**

R0)
$$(x_1+y_1\mathbf{i})(x_2+y_2\mathbf{i})=(x_1x_2-y_1y_2)+(x_1y_2+x_2y_1)\mathbf{i}$$
$$\overline{x+y\mathbf{i}}=x-y\mathbf{i}, \qquad |x+y\mathbf{i}|=\sqrt{x^2+y^2}, \qquad d(z_1,z_2)=|z_1-z_2|$$

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

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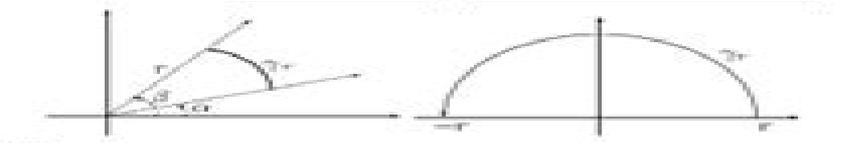$$e^z=1+\frac{z}{1!}+\frac{z^2}{2!}+\frac{z^3}{3!}+\dots \quad \text{for any } z$$

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 $\mathbf{Res}_{z_0}f=a_{-1}=\frac{1}{(k-1)!}\lim_{z\to z_0}\left((z-z_0)^k f(z)\right)^{(k-1)}$

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

R4 **Theorem of Residues.** For an open set $D\subseteq\mathbb{C}$:
$$\left. \begin{array}{l} f:D\longrightarrow\mathbb{C} \text{ holomorphic function} \\ S \text{ set of isolated singular points} \\ \gamma \text{ path homotopic to zero in } D\cup S \end{array} \right\} \Rightarrow \begin{array}{l} \int_\gamma f(z)dz= \\ =2\pi\mathbf{i}\sum_{z\in S} n(z,\gamma)\mathbf{Res}_z f \end{array}$$

R4 **Lemma 1.** For $\gamma_r:[\alpha,\beta]\longrightarrow\mathbb{C}, \gamma_r(t)=re^{\mathbf{i}t}$
$$\lim_{z\to\infty} z\,f(z)=0 \Rightarrow \lim_{r\to\infty}\int_{\gamma_r} f(z)\,dz=0$$

R5 **Lemma 2 (Jordan).** For $\gamma_r:[0,\pi]\longrightarrow\mathbb{C}, \gamma_r(t)=re^{\mathbf{i}t}$
$$\lim_{z\to\infty} f(z)=0 \Rightarrow \lim_{r\to\infty}\int_{\gamma_r} f(z)e^{iz}\,dz=0$$

A **Problems**

1 $(1-2i)^3=?, \qquad \frac{1+i}{3-4i}=?, \qquad e^{\frac{1+i}{2}\pi}=?, \qquad d(1+i,2-i)=?,$
$(z\sin z)'=?, \qquad (e^{z^2})'=?, \qquad \lim_{z\to\infty}\left(\frac{z}{z+1}+\frac{1}{z}\mathbf{i}\right)=?.$

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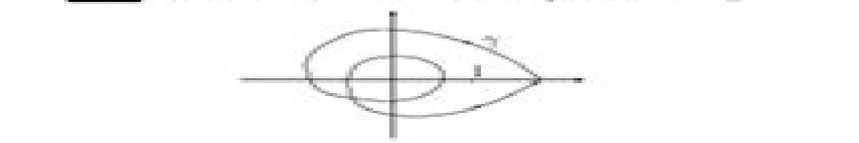$$f_1(z)=e^{z^2}, \qquad f_2(z)=z\,e^{\frac{1}{z}}, \qquad f_3(z)=\frac{1}{z-z^2}$$

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

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

B **Problems**

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

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

3 Compute the integral $\int_\gamma \frac{1}{z^2(1-z)}\,dz$ where γ is the path from the figure above.
Solution. By using the theorem of residues, we get
$$\int_\gamma \frac{1}{z^2(1-z)}\,dz=2\pi\mathbf{i}(2\,\mathbf{Res}_1 f+\mathbf{Res}_0 f)=2\pi\mathbf{i}.$$

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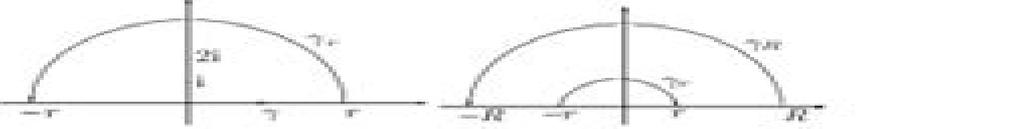
C **Problems**

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

2 Compute the integrals $I_1=\int_0^{2\pi}\frac{1}{2+\cos t}\,dt$ and $I_2=\int_0^{2\pi}\frac{1}{2+\cos t}\,dt$
Solution. By using the path $\gamma:[0,2\pi]\longrightarrow\mathbb{C}, \gamma(t)=e^{it}$, we get
$I_1=\int_0^{2\pi}\frac{1}{2+\frac{e^{it}+e^{-it}}{2}}\,dt=\int_0^{2\pi}\frac{2}{4+e^{it}+e^{-it}}\,dt$
$=-\mathbf{i}\int_\gamma \frac{1}{z}\frac{2}{4+z+\frac{1}{z}}\,dz=-\mathbf{i}\int_\gamma\frac{2}{z^2+4z+1}\,dz=2\pi\mathbf{Res}_{-2+\sqrt{3}}\frac{2}{z^2+4z+1}=\frac{2\pi}{\sqrt{3}}$

3 Compute the integrals $\int_0^\infty \frac{x^2}{(x^2+1)(x^2+4)}\,dx; \quad \int_0^\infty \frac{x^2}{(x^2+4)(x^2+9)}\,dx$
Solution. The integral is convergent: at infinity $\frac{x^2}{(x^2+1)(x^2+4)}\sim \frac{1}{x^2}$.
By using $\gamma_r:[0,\pi]\longrightarrow\mathbb{C}, \gamma_r(t)=re^{it}$ and $f(z)=\frac{z^2}{(z^2+1)(z^2+4)}$, we get
$\int_{\gamma_r} f(z)dz+\int_{-r}^r f(x)dx=2\pi\mathbf{i}(\mathbf{Res}_i f+\mathbf{Res}_{2i} f),$ whence
$\lim_{r\to\infty}\int_{\gamma_r} f(z)dz+\int_{-\infty}^\infty f(x)dx=2\pi\mathbf{i}(\mathbf{Res}_i f+\mathbf{Res}_{2i} f).$
Since $|z\,f(z)|=\frac{|z|^3}{|z^2+1||z^2+4|}\leq\frac{|z|^3}{(|z|^2-1)(|z|^2-4)},$
we have $\lim_{z\to\infty} z\,f(z)=0$ and in view of lemma 1, $\lim_{r\to\infty}\int_{\gamma_r} f(z)dz=0.$
Consequently, $\int_0^\infty f(x)dx=\pi\mathbf{i}(\mathbf{Res}_i f+\mathbf{Res}_{2i} f)=\frac{\pi}{6}.$

4 Prove that $\int_0^\infty\frac{\sin x}{x}=\frac{\pi}{2}$ (Poisson's integral).
Solution. Let $0<r<R$ and $\gamma_R,\gamma_r:[0,\pi]\longrightarrow\mathbb{C}, \gamma_R(t)=Re^{it}, \gamma_r(t)=re^{i(\pi-t)}$
From the residue theorem (right hand side of fig.) it follows the relation
$\int_{\gamma_R}\frac{e^{iz}}{z}\,dz+\int_{-R}^{-r}\frac{e^{ix}}{x}\,dx+\int_{\gamma_r}\frac{e^{iz}}{z}\,dz+\int_r^R\frac{e^{ix}}{x}\,dx=0,$ that is
$\int_{\gamma_R}\frac{e^{iz}}{z}\,dz+\int_{\gamma_r}\frac{e^{iz}}{z}\,dz+\int_r^R\frac{e^{ix}-e^{-ix}}{x}\,dx=0,$
$\int_{\gamma_R}\frac{e^{iz}}{z}\,dz+\int_{\gamma_r}\frac{1}{z}\,dz+\int_r^R\frac{e^{ix}-e^{-ix}}{x}\,dx=2\mathbf{i}\int_r^R\frac{\sin x}{x}\,dx=0.$
If g is an antiderivative of $f(z)=\frac{e^{iz}-1}{z}$, by using $\int_{\gamma_r}\frac{1}{z}\,dz=-\pi\mathbf{i}$, we get
$\int_{\gamma_R}\frac{e^{iz}}{z}\,dz-\pi\mathbf{i}+(g(r)-g(-r))+2\mathbf{i}\int_r^R\frac{\sin x}{x}\,dx=0.$
But, in view of Jordan's lemma $\lim_{R\to\infty}\int_{\gamma_R}\frac{e^{iz}}{z}=0,$
and for $R\to\infty$ and $r\to 0$ we get $2\mathbf{i}\int_0^\infty\frac{\sin x}{x}\,dx=\pi\mathbf{i}$

5 Find the holomorphic function $f:\mathbb{C}\longrightarrow\mathbb{C}$ with $\begin{array}{l}\mathfrak{Im}\,f(x+y\mathbf{i})=2xy-2x, \\ f(i)=0.\end{array}$

6 For $z_0\neq 0$, expand $f:\mathbb{C}^*\longrightarrow\mathbb{C}, f(z)=\frac{1}{z}$ 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 $|z-z_0|<|z_0|$;
$f(z)=\frac{1}{z_0+z-z_0}=\frac{1}{z-z_0}\frac{1}{1+\frac{z_0}{z-z_0}}=\frac{1}{z-z_0}\left(1-\frac{z_0}{(z-z_0)}+\frac{z_0^2}{(z-z_0)^2}-\dots\right),$
for $|z-z_0|>|z_0|$.

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

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AN Whitehead

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web analysis construct a solubility curve using the mass of solute that will dissolve in 100 g of water at a specified temperature in this lab 5 ml of water was used assume 1 0 g ml of water take the collected data make it proportional to get the solubility of the kno3 graph temperature vs solubility using a best fit curve

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web part i construct a single graph with multiple solubility curves to clearly show the solubility of the four ionic compounds

in the data table below the following tips will help you make the best possible graph

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