COMPLEX ANALYSIS - Problems

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

B Fundamental definitions and results

B0 $(x_1+y_1\mathrm{i})(x_2+y_2\mathrm{i})=(x_1x_2-y_1y_2)+(x_1y_2+x_2y_1)\mathrm{i}$

$\overline{x+y\mathrm{i}}=x-y\mathrm{i}, \quad |x+y\mathrm{i}|=\sqrt{x^2+y^2}, \quad d(z_1,z_2)=|z_1-z_2|$

B1 $\frac{1}{1-z}=1+z+z^2+z^3+\ldots$ for $|z|<1$

B2 $e^z=1+\frac{z}{1!}+\frac{z^2}{2!}+\frac{z^3}{3!}+\ldots$ for any z

B3 In the neighbourhood of a pole z_0 of order k

$f(z)=\frac{a_{-k}}{(z-z_0)^k}+\ldots+\frac{a_{-1}}{(z-z_0)}+a_0+a_1(z-z_0)+\ldots$

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

B4 Complex integral of $f:D\longrightarrow\mathbb{C}$ along $\gamma:[a,b]\longrightarrow D$ is

$$\int_\gamma f(z)dz=\int_a^b f(\gamma(t))\,\gamma'(t)dt$$

B4 **Theorem of Residues.** For an open set $D\subset\mathbb{C}$:

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

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

B4 **Lemma 1.** For $\gamma_r:[\alpha,\beta]\to\mathbb{C}$, $\gamma_r(t)=re^{it}$

$\lim_{z\to\infty} zf(z)=0 \Rightarrow \lim_{r\to\infty}\int_{\gamma_r}f(z)\,dz=0$

B5 **Lemma 2 (Jordan).** For $\gamma_r:[0,\pi]\to\mathbb{C}$, $\gamma_r(t)=re^{it}$

$\lim_{z\to\infty}f(z)=0 \Rightarrow \lim_{r\to\infty}\int_{\gamma_r}f(z)e^{iz}dz=0$

A Problems

1 $(1-2\mathrm{i})^3=?$, $\frac{1-\mathrm{i}}{2-4\mathrm{i}}=?$, $e^{\frac{\pi}{2}\mathrm{i}}=?$, $d(1+\mathrm{i},2-\mathrm{i})=?$,

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

2 Expand in a power series of z the functions

$f_1(z)=e^{z^2}$, $f_2(z)=z\,e^{\frac{1}{z}}$, $f_3(z)=\frac{1}{z^2-5z+6}$

Solution.

$f_1(z)=1+\frac{z^2}{1!}+\frac{z^4}{2!}+\frac{z^6}{3!}+\ldots$ for any z.

$f_2(z)=z\left(1+\frac{1}{1!}\frac{1}{z}+\frac{1}{2!}\frac{1}{z^2}+\frac{1}{3!}\frac{1}{z^3}+\ldots\right)=\ldots+\frac{1}{3!}\frac{1}{z^2}+\frac{1}{2!}\frac{1}{z}+1+z$ for $|z|>0$.

$f_3(z)=\frac{1}{z^2}\left(1+z+z^2+z^3+\ldots\right)=\frac{1}{z^2}+\frac{1}{z}+1+z+\ldots$ 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.

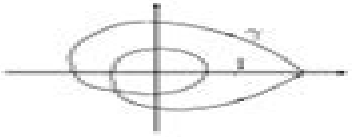
B Problems

1 Prove that $f:\mathbb{C}\longrightarrow\mathbb{C}$, $f(z)=1+z$ is not $\mathbb{C}$-differentiable.

Hint. Use the Cauchy-Riemann theorem.

2 For $\gamma:[0,\pi]\longrightarrow\mathbb{C}$, $\gamma(t)=e^{it}$, compute $\int_\gamma(z+\bar{z})\,dz$.

Hint. Use the definition of the complex line integral.



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

Solution. By using the theorem of residues, we get

$\int_\gamma \frac{1}{z^2(z-2)}dz=2\pi\mathrm{i}(2\,\mathbf{Res}_0 f+\mathbf{Res}_2 f)=2\pi\mathrm{i}$.

4 Compute the residue of $f(z)=z\,e^{\frac{1}{z}}$ at the singular point $z_0=0$.

Solution. $f(z)=\ldots+\frac{1}{3!}\frac{1}{z^2}+\frac{1}{2!}\frac{1}{z}+1+z$ for any z $\Rightarrow$ $\mathbf{Res}_0 f=\frac{1}{2}$.

C Problems

1 Compute the residues of $f(z)=z^2e^{\frac{z}{z-1}}$ at the singular point $z_0=1$.

Hint. $f(z)=\left((z-1)^2+2(z-1)+1\right)\left(1+\frac{1}{1!}\frac{1}{z-1}+\frac{1}{2!}\frac{1}{(z-1)^2}+\frac{1}{3!}\frac{1}{(z-1)^3}+\ldots\right)$.

2 Compute the integrals $I_1=\int_0^{2\pi}\frac{1}{2+\sin t}dt$ 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

$I_1=\int_0^{2\pi}\frac{1}{2+\frac{1}{2\mathrm{i}}\left(e^{it}-e^{-it}\right)}dt=\int_0^{2\pi}\frac{1}{1+\mathrm{i}+\frac{z^2}{2\mathrm{i}z}}(e^{it})'\,dt$

$=-\mathrm{i}\int_\gamma\frac{1}{\frac{z}{2}+\mathrm{i}+\frac{1}{2z}}dz=-\mathrm{i}\int_\gamma\frac{2}{z^2+2\mathrm{i}z+1}dz=2\pi\mathbf{Res}_{-2+\sqrt{3}}\frac{2}{z^2+2\mathrm{i}z+1}=\frac{2\pi}{\sqrt{3}}$

3 Compute the integrals $\int_0^\infty\frac{x^2}{(x^2+1)(x^2+4)}dx$, $\int_0^\infty\frac{x^2}{(x^2+1)(x^2+9)}dx$

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

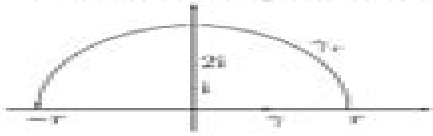
$\int_{\gamma_r}f(z)dz+\int_{-r}^{r}f(x)dx=2\pi\mathrm{i}\left(\mathbf{Res}_{\mathrm{i}}f+\mathbf{Res}_{2\mathrm{i}}f\right)$, whence

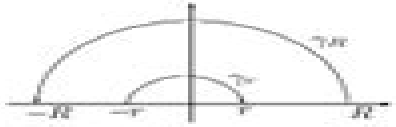
$\lim_{r\to\infty}\int_{\gamma_r}f(z)dz+\int_{-\infty}^{\infty}f(x)dx=2\pi\mathrm{i}\left(\mathbf{Res}_{\mathrm{i}}f+\mathbf{Res}_{2\mathrm{i}}f\right)$.

Since $|z\,f(z)|=\frac{|z^3|}{|z^2+1||z^2+4|}=\frac{|z^3|}{|z^2-(-1)||z^2-(-4)|}\le\frac{|z|^3}{(|z|^2-1)(|z|^2-4)}$,

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, $\int_0^\infty f(x)dx=\pi\mathrm{i}\left(\mathbf{Res}_{\mathrm{i}}f+\mathbf{Res}_{2\mathrm{i}}f\right)=\frac{\pi}{6}$.





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

Solution. Let $0<r<R$ and $\gamma_R,\gamma_r:[0,\pi]\to\mathbb{C}$, $\gamma_R(t)=Re^{it}$, $\gamma_r(t)=r\,e^{i(\pi-t)}$.

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

$\int_{\gamma_R}\frac{e^{iz}}{z}dz+\int_{\gamma_r}\frac{e^{iz}}{z}dz+\int_r^R\frac{e^{ix}-e^{-ix}}{x}dx=0$,

$\int_{\gamma_R}\frac{e^{iz}}{z}dz+\int_{\gamma_r}\frac{1}{z}dz+\int_{\gamma_r}\frac{e^{iz}-1}{z}dz+2\mathrm{i}\int_r^R\frac{\sin x}{x}dx=0$.

If g is an antiderivative of $f(z)=\frac{e^{iz}-1}{z}$, by using $\int_{\gamma_r}\frac{1}{z}dz=-\pi\mathrm{i}$, we get

$\int_{\gamma_R}\frac{e^{iz}}{z}dz-\pi\mathrm{i}+\left(g(r)-g(-r)\right)+2\mathrm{i}\int_r^R\frac{\sin x}{x}dx=0$.

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 $r\to0$ we get $2\mathrm{i}\int_0^\infty\frac{\sin x}{x}dx=\pi\mathrm{i}$.

5 Find the holomorphic function $f:\mathbb{C}\to\mathbb{C}$ with $\begin{matrix}\mathrm{Re}\,f(x+y\mathrm{i})=2xy-2x,\\ f(\mathrm{i})=0.\end{matrix}$

6 For $z_0\neq0$, expand $f:\mathbb{C}^*\to\mathbb{C}$, $f(z)=\frac{1}{z}$ in a power series of $(z-z_0)$.

Solution. We have

$f(z)=\frac{1}{z_0+z-z_0}=\frac{1}{z_0}\frac{1}{1-\frac{z-z_0}{-z_0}}=\frac{1}{z_0}\left(1-\frac{1}{z_0}(z-z_0)+\frac{1}{z_0^2}(z-z_0)^2-\ldots\right)$

for $|z-z_0|<|z_0|$;

$f(z)=\frac{1}{z_0+z-z_0}=\frac{1}{z-z_0}\frac{1}{1-\frac{z_0}{z-z_0}}=\frac{1}{z-z_0}\left(1-\frac{z_0}{(z-z_0)}+\frac{z_0^2}{(z-z_0)^2}-\ldots\right)$,

for $|z-z_0|>|z_0|$.

7 Expand in a power series of $(z-1)$ the functions:

$f_1(z)=\frac{1}{z}$, $f_2(z)=\frac{1}{z^2+z}$, $f_3(z)=\frac{1}{z}+\frac{1}{z^2+z}$.

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all known conformal maps to date with diagrams and description and all possible applications in different scientific disciplines such as fluid flows heat transfer acoustics electromagnetic fields as static fields in electricity and magnetism various mathematical models and methods including solutions of certain integral equations A First Course in Complex Analysis with Applications Dennis G. Zill,Patrick Shanahan,Patrick D. Shanahan,2006-07 A First Course In Complex Analysis With Applications Limits Theoretical Coverage To Only What Is Necessary And Conveys It In A Student Friendly Style Its Aim Is To Introduce The Basic Principles And Applications Of Complex Analysis To Undergraduates Who Have No Prior Knowledge Of This Subject Contents Of The Book Include The Complex Number System Complex Functions And Sequences As Well As Real Integrals In Addition To Other Concepts Of Calculus And The Functions Of A Complex Variable This Text Is Written For Junior Level Undergraduate Students Who Are Majoring In Math Physics Computer Science And Electrical Engineering *Digital Technologies and Institutions for Sustainable Development* Aleksei V. Bogoviz,Elena G. Popkova,2022-10-11 This book focuses on digital institutions and the advanced technologies used on their basis as well as their contribution to sustainable development in the unity of seventeen SDGs formulated by the UN which is sequentially disclosed in six parts of the book This book is dedicated to comprehensive coverage of the role of the digital economy in sustainable development and the offering of a set of scientific methodological and practical recommendations to increase the scale and effectiveness of this role The first part explores the training of digital personnel for sustainable development the second part reveals the regional features of Russia and the third part describes the industry specifics of using digital technologies in entrepreneurship in support of sustainable development The fourth part deals with financial organizational and managerial issues of using digital technologies in entrepreneurship in support of sustainable development the fifth part is devoted to security international factors and risks and the sixth part deals with the legal framework and state regulation of digital technologies and sustainable development institutions The novelty of the book lies in its reliance on an institutional approach that allows rethinking and systematically studying the contribution of the digital economy to sustainable development The book is aimed at scholars who will find in it an institutional understanding of the digital economy s support for sustainable development and ways to improve it The secondary target audience of the book is the subject of managing the sustainable development of the digital economy For them the book contains relevant and illustrative examples from practice and applied recommendations **Complex Analysis with Applications** Nakhlé H. Asmar,Loukas Grafakos,2018-10-12 This textbook is intended for a one semester course in complex analysis for upper level undergraduates in mathematics Applications primary motivations for this text are presented hand in hand with theory enabling this text to serve well in courses for students in engineering or applied sciences The overall aim in designing this text is to accommodate students of different mathematical backgrounds and to achieve a balance between presentations of rigorous mathematical proofs and applications The text is adapted to enable maximum flexibility to instructors and to students who may also choose to progress

through the material outside of coursework Detailed examples may be covered in one course giving the instructor the option to choose those that are best suited for discussion Examples showcase a variety of problems with completely worked out solutions assisting students in working through the exercises The numerous exercises vary in difficulty from simple applications of formulas to more advanced project type problems Detailed hints accompany the more challenging problems Multi part exercises may be assigned to individual students to groups as projects or serve as further illustrations for the instructor Widely used graphics clarify both concrete and abstract concepts helping students visualize the proofs of many results Freely accessible solutions to every other odd exercise are posted to the book s Springer website Additional solutions for instructors use may be obtained by contacting the authors directly *A Collection of Problems on Complex Analysis* Lev Izrailevich Volkovyskiĭ,G. L. Lunts,Isaak Genrikhovich Aramanovich,1991 This comprehensive collection contains over 1 500 problems on the theory of functions of the complex variable and covers nearly every branch of classical function theory It will be of special interest to practicing engineers and researchers in the physical sciences for considerable attention is given to those problems which illustrate the application of the theory of functions of a complex variable to problems dealing with the mechanics of continuous media and electrical engineering The problems themselves range in difficulty from elementary to those encountered only in more advanced treatments The first four chapters involve complex numbers and functions of a complex variable conformal mappings connected with elementary functions supplementary geometrical questions and generalized analytic functions and integrals and power series Chapters V through VIII cover the Launrent series singularities of single valued functions and integral functions various series of functions parametric integrals and infinite products residues and their applications integrals of the Cauchy type and integral functions of Poisson and Schwarz The final three chapters discuss analytic continuation singularities of many valued character and Riemann Surfaces conformal mappings and applications to mechanic and physics Answers and solutions are grouped at the end of the text **Advances in Interdisciplinary Mathematical Research** Bourama Toni,2014-07-08 This volume contains the invited contributions to the Spring 2012 seminar series at Virginia State University on Mathematical Sciences and Applications It is a thematic continuation of work presented in Volume 24 of the Springer Proceedings in Mathematics almost stochastic difference equations absolute and conditional stability in delayed equations gamma convergence and applications to block copolymer morphology the dynamics of collision and near collision in celestial mechanics almost and pseudo almost limit cycles rainbows in spheres and connections to ray wave and potential scattering theory null controllability of the heat equation with constraints optimal control for systems subjected to null controllability the Galerkin method for heat transfer in closed channels wavelet transforms for real time noise cancellation signal image processing and machine learning in medicine and biology methodology for research on durability reliability damage tolerance of aerospace materials and structures at NASA Langley Research Center The volume is suitable and valuable for mathematicians scientists and research students in a

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Zill,Patrick D. Shanahan,2013-09-20 Designed for the undergraduate student with a calculus background but no prior experience with complex analysis this text discusses the theory of the most relevant mathematical topics in a student friendly manner With a clear and straightforward writing style concepts are introduced through numerous examples illustrations and applications Each section of the text contains an extensive exercise set containing a range of computational conceptual and geometric problems In the text and exercises students are guided and supported through numerous proofs providing them with a higher level of mathematical insight and maturity Each chapter contains a separate section devoted exclusively to the applications of complex analysis to science and engineering providing students with the opportunity to develop a practical and clear understanding of complex analysis The Mathematica syntax from the second edition has been updated to coincide with version 8 of the software

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