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

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

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

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 $D\subseteq\mathbb{C}$:

$f:D\longrightarrow\mathbb{C}$ holomorphic function
S set of isolated singular points
γ path homotopic to zero in $D\backslash S$
$\Rightarrow$ $\int_\gamma f(z)dz=2\pi\mathrm{i}\sum_{z\in S}n(z,\gamma)\mathbf{Res}_z f$

R4 **Lemma 1.** For $\gamma_r:[\alpha,\beta]\longrightarrow\mathbb{C},\ \gamma_r(t)=re^{\mathrm{i}t}$

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

R5 **Lemma 2 (Jordan).** For $\gamma_r:[0,\pi]\longrightarrow\mathbb{C},\ \gamma_r(t)=re^{\mathrm{i}t}$

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

A **Problems**

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

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

2 Expand in a power series of z the functions

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

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 $|z|>0$.

$f_3(z)=\frac{1}{z^2}(1+z+z^2+z^3+\dots)=\frac{1}{z^2}+\frac{1}{z}+1+z+\dots,$ 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 $f:\mathbb{C}\longrightarrow\mathbb{C},\ f(z)=1+\bar z$ is not $\mathbb{C}$-differentiable.

Hint. Use the Cauchy-Riemann theorem.

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

Hint. Use the definiton of the complex line integral.
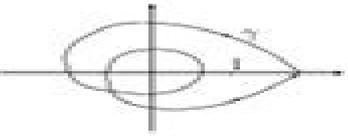
3 Compute the integral $\int_\gamma\frac{1}{z^2(1-z)}\,dz$ where γ is the path from the figure above.

Solution. By using the theorem of residues, we get

$\int_\gamma\frac{1}{z^2(1-z)}\,dz=2\pi\mathrm{i}(2\,\mathbf{Res}_0 f+\mathbf{Res}_1 f)=2\pi\mathrm{i}.$

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

Solution. $f(z)=\dots+\frac{1}{3!}\frac{1}{z^2}+\frac{1}{2!}\frac{1}{z}+1+z$ 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 $\gamma:[0,2\pi]\longrightarrow\mathbb{C},\ \gamma(t)=e^{\mathrm{i}t}$, we get

$I_1=\int_0^{2\pi}\frac{1}{2+\frac{e^{it}+e^{-it}}{2}}\,dt=\int_0^{2\pi}\frac{2}{4+e^{it}+e^{-it}}\,dt$

$=-\mathrm{i}\int_\gamma\frac{1}{z}\frac{2}{4+z+\frac{1}{z}}\,dz=-\mathrm{i}\int_\gamma\frac{2}{z^2+4z+1}\,dz=2\pi\,\mathbf{Res}_{-2+\sqrt3}\frac{2}{z^2+4z+1}=\frac{2\pi}{\sqrt3}$

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

Solution. The integral is convergent; at infinity $\frac{x^2}{(x^2+1)(x^2+4)}\sim\frac{1}{x^2}$.
By using $\gamma_r:[0,\pi]\longrightarrow\mathbb{C},\ \gamma_r(t)=re^{\mathrm{i}t}$ and $f(z)=\frac{z^2}{(z^2+1)(z^2+4)}$, we get

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

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

Since $|z\,f(z)|=\frac{|z|^3}{|z^2+1||z^2+4|}\le\frac{|z|^3}{(|z|^2-1)(|z|^2-4)},$
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, $\int_0^\infty f(x)dx=\pi\mathrm{i}(\mathbf{Res}_i f+\mathbf{Res}_{2i}f)=\frac{\pi}{6}.$


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

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

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

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

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

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

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 $r\to 0$ we get $2\mathrm{i}\int_0^\infty\frac{\sin x}{x}\,dx=\pi\mathrm{i}$

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

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:

$f_1(z)=\frac{1}{z},\qquad f_2(z)=\frac{1}{z-2i},\qquad f_3(z)=\frac{1}{z}+\frac{1}{z-2i}.$
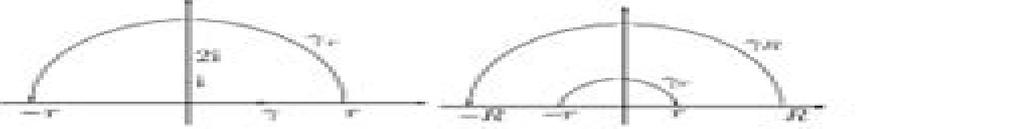
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text is to accommodate students of different mathematical backgrounds and to achieve a balance between presentations of rigorous mathematical proofs and applications The text is adapted to enable maximum flexibility to instructors and to students who 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   <u>A Complex Analysis Problem Book</u> Daniel Alpay,2016-10-26 This second edition presents a collection of exercises on the theory of analytic functions including completed and detailed solutions It introduces students to various applications and aspects of the theory of analytic functions not always touched on in a first course while also addressing topics of interest to electrical engineering students e g the realization of rational functions and its connections to the theory of linear systems and state space representations of such systems It provides examples of important Hilbert spaces of analytic functions in particular the Hardy space and the Fock space and also includes a section reviewing essential aspects of topology functional analysis and Lebesgue integration Benefits of the 2nd edition Rational functions are now covered in a separate chapter Further the section on conformal mappings has been expanded   **Problems and Solutions in Real Analysis** Masayoshi Hata,2007 This unique book provides a collection of more than 200 mathematical problems and their detailed solutions which contain very useful tips and skills in real analysis Each chapter has an introduction in which some fundamental definitions and propositions are prepared This also contains many brief historical comments on some significant mathematical results in real analysis together with useful references Problems and Solutions in Real Analysis may be used as advanced exercises by undergraduate students during or after courses in calculus and linear algebra It is also useful for graduate students who are interested in analytic number theory Readers will also be able to completely grasp a simple and elementary proof of the prime number theorem through several exercises The book is also suitable for non experts who wish to understand mathematical analysis   **Complex Analysis** Dennis G. 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

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and then examines its geometrical interpretation and application to Dirichlet and Neumann boundary value problems p

   Complex Analysis and Differential Equations Luis Barreira,Claudia Valls,2012-04-23 This text provides an accessible self contained and rigorous introduction to complex analysis and differential equations Topics covered include holomorphic functions Fourier series ordinary and partial differential equations The text is divided into two parts part one focuses on complex analysis and part two on differential equations Each part can be read independently so in essence this text offers two books in one In the second part of the book some emphasis is given to the application of complex analysis to differential equations Half of the book consists of approximately 200 worked out problems carefully prepared for each part of theory plus 200 exercises of variable levels of difficulty Tailored to any course giving the first introduction to complex analysis or differential equations this text assumes only a basic knowledge of linear algebra and differential and integral calculus Moreover the large number of examples worked out problems and exercises makes this the ideal book for independent study

   Riemann-Hilbert Problems, Their Numerical Solution, and the Computation of Nonlinear Special Functions Thomas Trogdon,Sheehan Olver,2015-12-22 Riemann Hilbert problems are fundamental objects of study within complex analysis Many problems in differential equations and integrable systems probability and random matrix theory and asymptotic analysis can be solved by reformulation as a Riemann Hilbert problem This book the most comprehensive one to date on the applied and computational theory of Riemann Hilbert problems includes an introduction to computational complex analysis an introduction to the applied theory of Riemann Hilbert problems from an analytical and numerical perspective and a discussion of applications to integrable systems differential equations and special function theory It also includes six fundamental examples and five more sophisticated examples of the analytical and numerical Riemann Hilbert method each of mathematical or physical significance or both   *Complex Analysis* M. D. PETALE, Purpose of this Book The purpose of this book is to supply lots of examples with details solution that helps the students to understand each example step wise easily and get rid of the college assignments phobia It is sincerely hoped that this book will help and better equipped the higher secondary students to prepare and face the examinations with better confidence I have endeavored to present the book in a lucid manner which will be easier to understand by all the engineering students About the Book According to many streams in engineering course there are different chapters in Engineering Mathematics of the same year according to the streams Hence students faced problem about to buy Engineering Mathematics special book that covered all chapters in a single book That s reason student needs to buy many books to cover all chapters according to the prescribed syllabus Hence need to spend more money for a single subject to cover complete syllabus So here good news for you your problem solved I made here special books according to chapter wise which helps to buy books according to chapters and no need to pay extra money for unneeded chapters that not mentioned in your syllabus PREFACE It gives me great pleasure to present to you this book on A Textbook on Complex Analysis of Engineering Mathematics presented specially for you Many books have been written

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