MA2287: Complex Analysis Exam Notes

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Prelims

Completing a Square

Definition

> **Definition**
>
> Given a quadratic expression $x^2 + bx$, we can complete the square by following these steps:
>
> $$\left(\frac{b}{2}\right)^2 \qquad\qquad \textit{Determine the term to complete the square:}$$
>
> $$x^2 + bx = \left(x^2 + bx + \left(\frac{b}{2}\right)^2\right) - \left(\frac{b}{2}\right)^2 \qquad \textit{Add and subtract this term:}$$
>
> $$x^2 + bx + \left(\frac{b}{2}\right)^2 = \left(x + \frac{b}{2}\right)^2 \qquad\qquad \textit{Rewrite as a perfect square:}$$
>
> $$x^2 + bx = \left(x + \frac{b}{2}\right)^2 - \left(\frac{b}{2}\right)^2 \qquad\qquad \textit{Thus the expression becomes}$$

1 Question 1:

1.1 Sketch the region in the complex plane determined by the inequality

- $|z - 4| > 3|z + 4|$ 2023 Q1(a)

- $\{z \in \mathbb{C} : |2z - 1| < 2|2z - i|\}$ 2022 Q1(a), 2021 Q1(d), 2017 Q1(a), 2016 Q1(a)

1.2 Determine all solutions to roots of unity

- $z^6 - 1 = 0$ and factorize $x^6 - 1$ as a product of linear and quadratic factors   2023 Q1(b),

- $z^4 = -81i$ and find a polynomial $p(z)$ with complex coefficients with root w and $p(\overline{w}) \neq 0$ 2022 Q1(b), 2018 Q1(b)

- $z^6 - 1 = 0$ and factorize $x^6 - 1$ as a product of linear and quadratic factors   2021 Q1(c)

- $z^3 = 1 + i$, let $n \in \mathbb{N}$ and $w \neq 1$ be an n-th root of unity. Prove $1 + w + w^2 + \ldots + w^{n-1} = 0$ 2016 Q1(c)

1.3 Determine and sketch the image under the mapping

- $w = e^z$, $\{z \in \mathbb{C} : \pi/4 \leq \text{Im}(z) \leq \pi/2\}$ 2023 Q1(c), 2021 Q1(a), 2017 Q1(d)

- $w = \text{Log}(z)$, $\{z : |z| > 1, 0 \leq \text{Arg}(z) \leq \pi/2\}$ 2022 Q1(d), 2018 Q1(d), 2016 Q1(d)

1.4 Find z where the function is 0

- $\cos(z) = \frac{e^{iz} + e^{-iz}}{2}$ 2022 Q1(d)

1.5 Calculate principal value Log(z)

- $z = -\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}i$ and prove e^z is the inverse function of Log(z)   2022 Q1(c), 2018 Q1(c), 2017 Q1(c)

1.6 Prove the following

- Define the complex conjugate $(\overline{w})$ and prove if w is a zero of a polynomial $p(z) = a_0 + a_1 z + \ldots + a_n z^n$ then $\overline{w}$ is also a zero of $p(z)$ 2021 Q1(b), 2018 Q1(a), 2016 Q1(b)

- Define the complex exponential function e^z and prove Eulers Formula $e^{i\theta} = \cos(\theta) + i\sin(\theta)$ 2017 Q1(b)

Example 2023 Q1(a)

Given $|z - 4| > 3|z + 4|$
Write $z = x + iy$

$$|x + iy - 4| > 3|x + iy + 4|$$
$$|(x - 4) + iy| > 3|(x + 4) + iy|$$
$$\sqrt{(x - 4)^2 + y^2} > 3\sqrt{(x + 4)^2 + y^2}$$

Square both sides

$$(x - 4)^2 + y^2 > 9((x + 4)^2 + y^2)$$
$$(x^2 - 8x + 16 + y^2) > 9x^2 + 72x + 144 + 9y^2$$
$$x^2 - 8x + 16 + y^2 - 9x^2 - 72x - 144 - 9y^2 > 0 \qquad\qquad \textit{Moving all terms to one side}$$
$$-8x^2 - 80x - 8y^2 - 128 > 0 \qquad\qquad \textit{Simplify}$$
$$x^2 + 10x + y^2 - 16 < 0 \qquad\qquad \textit{Dividing by -8 and reversing inequality}$$

Focus on x and complete the square

$$x^2 + bx = x^2 + 10x \Rightarrow \left(\frac{b}{2}\right)^2 = \left(\frac{10}{2}\right)^2 = (5)^2 = 25$$

2 Question 2:

2.1 Determine image of the line

- $f(z) = \frac{1}{z}$ $\{z \in \mathbb{C} : \operatorname{Re}(z) = 2\}$ 2023 Q2(a), 2021 Q2(b)

- $f(z) = \frac{1}{z}$ $\{z \in \mathbb{C} : \operatorname{Re}(z) = 1\}$ 2022 Q2(a), 2018 Q2(a), 2017 Q2(a)

2.2 State and Use Cauchy-Riemann Equations

- State CRE, and use to prove $f(z) = \frac{1}{z}$ is holomoprhic on $\mathbb{C} \backslash \{0\}$ 2023 Q2(a)

- State CRE, and use to prove $f(z) = z^2$ is holomoprhic on $\mathbb{C}$ 2022 Q2(b)

- State CRE. Let $f = u + iv$ be holomoprhic on $\Omega \subset \mathbb{C}$. Prove ∇u and ∇v are perpendicular of equal length 2016 Q2(b)

2.3 Show that

- If $\overline{f(z)} = f(\overline{z})$ for all $z \in \mathbb{C}$ then $f(x)$ is real for all $x \in \mathbb{R}$. And if in addition f is holomoprhic at $x \in \mathbb{R}$ then $f'(x)$ is real.   2023 Q2(c)

- Define that is meant for a function g to be harmonic. If $f = u + iv$ is holomoprhic on $\Omega \subset \mathbb{C}$, prove that $v(x, y)$ is a harmonic function, and that ∇u and ∇v are perpendicular of equal length.   2022 Q2(c), 2018 Q2(b)

- If $\overline{f(z)} = f(\overline{z})$ for all $z \in \mathbb{C}$ then $f(x)$ is real for all $x \in \mathbb{R}$. And if in addition f is holomoprhic at 0 then the function $f'(0)$ is real.   2021 Q2(a), 2017 Q2(c)

- Let $f(z) = u + iv$ be holomoprhic on an open subset Ω of the complex plane and let $h(u, v)$ be a harmonic function of u and v on $f(\Omega)$. Prove that $g(x, y) = h(u(x, y), v(x, y))$ is harmonic on Ω (You may assume $\nabla u, \nabla v$ are equal length and perpendicular)   2021 Q2(c)

- Define what is meant for a function $f(z)$ to be holomoprhic at a point $z_0 \in \mathbb{C}$ and prove that $f(z) = z^2$ is holomoprhic and find its derivative there. Hence prove that the product uv is harmonic where $f = u + iv$ 2018 Q2(c)

- Define what is meant for a function $f(z)$ to be holomoprhic at a point $z_0 \in \mathbb{C}$ and prove that $f(z) = \frac{1}{z}$ is holomoprhic on $\mathbb{C} \backslash 0$ and find its derivative there (State any theorems used)   2017 Q2(b)

- Let $h(u, v)$ be a harmonic function of u, v on $f(\Omega)$ (See 2016 Q2(b)). Prove that $g(x, y) = h(u(x, y), v(x, y))$ is harmonic on Ω 2016 Q2(c)

2.4 Find Mobius Transformation

- $T(z) : (-1, 1, \infty) \mapsto (-1, -i, 1)$ 2023 Q2(d)

- $T(z) : (2, 1, -1) \mapsto (1, 0, \infty)$ 2022 Q2(d)

- $T(z) : (-i, -1, 1) \mapsto (1, 0, \infty)$ and find the inverse Mobius Transformation   2021 Q2(d)

- $T(z) : (-i, -1, i) \mapsto (1, 0, \infty)$ and find the inverse Mobius Transformation   2018 Q2(d), 2017 Q2(d)

- $T(z) : (-1, \frac{1}{2}, 2) \mapsto (1, 0, \infty)$ and find the inverse Mobius Transformation   2016 Q2(d)