

MA2287: Complex Analysis Exam Notes

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Contents

1	Question 1:	3
1.1	Sketch the region in the complex plane determined by the inequality	3
1.2	Determine all solutions to roots of unity	3
1.3	Determine and sketch the image under the mapping	3
1.4	Find z where the function is 0	3
1.5	Calculate principal value $\text{Log}(z)$	3
1.6	Prove the following	3
2	Question 2:	4
2.1	Determine image of the line	4
2.2	State and Use Cauchy-Riemann Equations	4
2.3	Show that	4
2.4	Find Mobius Transformation	4
3	Worked Examples - Q1	5
4	Worked Examples - Q2	11

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 $z^6 - 1$ as a product of linear and quadratic factors 2023 Q1(b), 2021 Q1(c)
- $z^4 = -81i$ and find a polynomial $p(z)$ with complex coefficients with root w and $p(\bar{w}) \neq 0$ 2022 Q1(b), 2018 Q1(b)

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 $\text{Log}(z)$

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

1.6 Prove the following

- Define the complex conjugate (\bar{w}) and prove if w is a zero of a polynomial $p(z) = a_0 + a_1z + \dots + a_nz^n$ then \bar{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)

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 holomorphic on $\mathbb{C} \setminus \{0\}$ 2023 Q2(a)
- State CRE, and use to prove $f(z) = z^2$ is holomorphic on \mathbb{C} 2022 Q2(b)
- State CRE. Let $f = u + iv$ be holomorphic on $\Omega \subset \mathbb{C}$. Prove ∇u and ∇v are perpendicular of equal length 2016 Q2(b)

2.3 Show that

- If $\overline{f(z)} = f(\bar{z})$ for all $z \in \mathbb{C}$ then $f(x)$ is real for all $x \in \mathbb{R}$. And if in addition f is holomorphic 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 holomorphic 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 $\overline{f(z)} = f(\bar{z})$ for all $z \in \mathbb{C}$ then $f(x)$ is real for all $x \in \mathbb{R}$. And if in addition f is holomorphic at 0 then the function $f'(0)$ is real. 2021 Q2(a), 2017 Q2(c)
- Let $f(z) = u + iv$ be holomorphic 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 holomorphic at a point $z_0 \in \mathbb{C}$ and prove that $f(z) = z^2$ is holomorphic 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 holomorphic at a point $z_0 \in \mathbb{C}$ and prove that $f(z) = \frac{1}{z}$ is holomorphic on $\mathbb{C} \setminus \{0\}$ 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)

3 Worked Examples - Q1

Example 3.1: 2023 Q1(a)

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

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

Square both sides

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

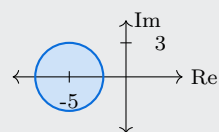
Focus on x and complete the square

$$\begin{aligned} x + bx &= \left(x + \frac{b}{2}\right)^2 - \left(\frac{b}{2}\right)^2 \Rightarrow x^2 + 10x = (x + 5)^2 - 25 && \text{Complete the square} \\ (x + 5)^2 - 25 + y^2 + 16 &< 0 && \text{Substitute back into inequality} \\ (x + 5)^2 + y^2 + 9 &< 0 && \text{Simplify} \\ (x + 5)^2 + y^2 &< -9 && \text{Subtract 9} \end{aligned}$$

Recall the equation of a circle

$$(x - a)^2 + (y - b)^2 = r^2 \Rightarrow (x + 5)^2 + y^2 < -9$$

Therefore the region is all the points inside circle with radius 3 and center at (-5, 0)



Example 3.2: 2022 Q1(a), 2021 Q1(d), 2017 Q1(a), 2016 Q1(a)

Given $\{z \in \mathbb{C} : |2z - 1| < 2|2z - i|\}$

Write $z = x + iy$

$$\begin{aligned}
 |2x + i2y - 1| &< 2|2x + i2y - i| \\
 |(2x - 1) + i2y| &< 2|2x + i(2y - 1)| \\
 \sqrt{(2x - 1)^2 + 4y^2} &< 2\sqrt{4x^2 + (2y - 1)^2} \\
 (2x - 1)^2 + 4y^2 &< 4[4x^2 + (2y - 1)^2] && \text{Square both sides} \\
 4x^2 - 4x + 1 + 4y^2 &< 16x^2 + 16y^2 - 16y + 4 && \text{Expand} \\
 -12x^2 - 4x - 12y^2 + 16y - 3 &< 0 && \text{Move all terms to one side} \\
 12x^2 + 4x + 12y^2 - 16y + 3 &> 0 && \text{Multiply by -1 and reverse inequality} \\
 x^2 + \frac{1}{3}x + y^2 - \frac{4}{3}y + \frac{1}{4} &> 0 && \text{Divide by 12}
 \end{aligned}$$

Complete square for x

$$x^2 + bx = \left(x + \frac{b}{2}\right)^2 - \left(\frac{b}{2}\right)^2 \Rightarrow x^2 + \frac{1}{3}x = \left(x + \frac{1}{6}\right)^2 - \left(\frac{1}{36}\right)$$

Complete square for y

$$y^2 + by = \left(y - \frac{2}{3}\right)^2 - \left(\frac{4}{9}\right)$$

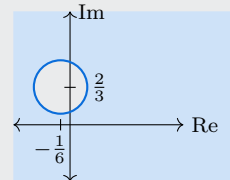
Substitute back into inequality

$$\begin{aligned}
 \left(x + \frac{1}{6}\right)^2 - \left(\frac{1}{36}\right) + \left(y - \frac{2}{3}\right)^2 - \left(\frac{4}{9}\right) + \frac{1}{4} &> 0 && \text{Substitute back into inequality} \\
 \left(x + \frac{1}{6}\right)^2 + \left(y - \frac{2}{3}\right)^2 &> \frac{2}{9} && \text{Simplify and move constant across}
 \end{aligned}$$

Recall the equation of a circle

$$(x - a)^2 + (y - b)^2 = r^2 \Rightarrow \left(x + \frac{1}{6}\right)^2 + \left(y - \frac{2}{3}\right)^2 < \frac{2}{9}$$

Therefore the region is all the points OUTSIDE the circle with radius $\frac{\sqrt{2}}{3}$ and center at $(-\frac{1}{6}, \frac{2}{3})$



Example 3.3: Determine all solutions to $z^6 - 1 = 0$ and factor $x^6 - 1$ as a product of linear and quadratic factors

Given $z^6 - 1 = 0$

Write $z = e^{i\theta}$ and $1 = e^{i2\pi k}$ for $k \in \mathbb{Z}$

$$\begin{aligned} z^6 - 1 &= 0 \\ e^{i6\theta} - e^{i2\pi k} &= 0 \\ e^{i6\theta} &= e^{i2\pi k} \\ 6\theta &= 2\pi k \\ \theta &= \frac{\pi k}{3} \end{aligned}$$

Therefore the solutions are

$$z = e^{i\theta} = e^{i\frac{\pi k}{3}} = \cos\left(\frac{\pi k}{3}\right) + i \sin\left(\frac{\pi k}{3}\right) \quad \text{for } k = 0, 1, 2, 3, 4, 5$$

$$k = 0 : w_0 = \cos(0) + i \sin(0) = 1 + i0$$

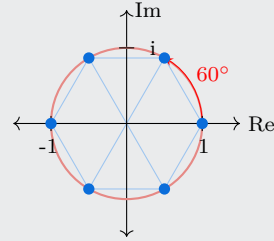
$$k = 1 : w_1 = \cos\left(\frac{\pi}{3}\right) + i \sin\left(\frac{\pi}{3}\right) = \frac{1}{2} + i \frac{\sqrt{3}}{2}$$

$$k = 2 : w_2 = \cos\left(\frac{2\pi}{3}\right) + i \sin\left(\frac{2\pi}{3}\right) = -\frac{1}{2} + i \frac{\sqrt{3}}{2}$$

$$k = 3 : w_3 = \cos(\pi) + i \sin(\pi) = -1$$

$$k = 4 : w_4 = \cos\left(\frac{4\pi}{3}\right) + i \sin\left(\frac{4\pi}{3}\right) = -\frac{1}{2} - i \frac{\sqrt{3}}{2}$$

$$k = 5 : w_5 = \cos\left(\frac{5\pi}{3}\right) + i \sin\left(\frac{5\pi}{3}\right) = \frac{1}{2} - i \frac{\sqrt{3}}{2}$$



We can write:

$$x^6 - 1 = (x - w_0)(x - w_1)(x - w_2)(x - w_3)(x - w_4)(x - w_5)$$

Rewriting to group complex conjugates

$$x^6 - 1 = (z - w_0)(z - w_3) \cdot (z - w_1)(z - w_5) \cdot (z - w_2)(z - w_4)$$

Note that

$$\begin{aligned} (w - z)(w - \bar{z}) &= w^2 - w\bar{z} - zw + z\bar{z} \\ &= w^2 - 2(\bar{z} + z) + 1 \end{aligned}$$

We recall that

$$\begin{aligned} z &= x + iy = e^{i\theta} = \cos(\theta) + i \sin(\theta) \\ \bar{z} &= x - iy = e^{-i\theta} = \cos(\theta) - i \sin(\theta) \end{aligned}$$

Then

$$\begin{aligned} \bar{z} + z &= \cos(\theta) + i \sin(\theta) + \cos(\theta) - i \sin(\theta) \\ &= 2 \cos(\theta) \end{aligned}$$

Thus

$$(w - z)(w - \bar{z}) = w^2 - 2 \cos(\theta) + 1$$

We see that $-\frac{5\pi}{3} = \frac{\pi}{3} - 2\pi$, thus:

$$(z - w_1)(z - w_5) = (z - e^{i\frac{\pi}{3}})(z - e^{i\frac{5\pi}{3}})$$

$$(z - w_1)(z - w_5) = z^2 - 2 \cos\left(\frac{\pi}{3}\right) + 1$$

$$(z - w_1)(z - w_5) = z^2 + z + 1$$

We see that $-\frac{4\pi}{3} = \frac{\pi}{3} - \pi$, thus:

$$(z - w_2)(z - w_4) = (z - e^{i\frac{2\pi}{3}})(z - e^{i\frac{4\pi}{3}})$$

$$(z - w_2)(z - w_4) = z^2 - 2 \cos\left(\frac{2\pi}{3}\right) + 1$$

$$(z - w_2)(z - w_4) = z^2 - z + 1$$

Therefore

$$x^6 - 1 = (x + 1)(x - 1)(x^2 + x + 1)(x^2 - x + 1)$$

Example 3.4: Determine all solutions to $z^4 = -81i$ and find a polynomial $p(z)$ with complex coefficients with root w and $p(\bar{w}) \neq 0$

Given $z^4 = -81i$, we want to find $z^{4(\frac{1}{4})} = w$

Recall:

$$z^{1/n} = R^{1/n} [\cos \phi + i \sin \phi] \quad \text{with } \phi = \frac{\theta + 2k\pi}{n}, \quad k \in (0, 1, 2, \dots, n-1) \quad \text{and } R = |z|$$

Thus

$$R = |-81i| = \sqrt{0^2 + 81^2} = 81$$

$$\theta = -\frac{\pi}{2}$$

$$\phi = \frac{\theta + 2k\pi}{n} = \frac{-\frac{\pi}{2} + 2k\pi}{4} = \frac{-\pi}{8} + \frac{k\pi}{2}$$

Therefore

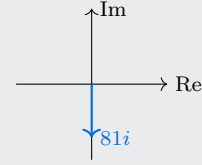
$$w_k = 81^{1/4} \left[\cos \left(\frac{-\pi}{8} + \frac{k\pi}{2} \right) + i \sin \left(\frac{-\pi}{8} + \frac{k\pi}{2} \right) \right] \quad k \in (0, 1, 2, 3)$$

$$w_0 = 3 \left[\cos \left(\frac{-\pi}{8} \right) + i \sin \left(\frac{-\pi}{8} \right) \right] \approx 2.77 - 1.155i$$

$$w_1 = 3 \left[\cos \left(-\frac{\pi}{8} + \frac{\pi}{2} \right) + i \sin \left(-\frac{\pi}{8} + \frac{\pi}{2} \right) \right] \approx 1.155 + 2.77i$$

$$w_2 = 3 \left[\cos \left(-\frac{\pi}{8} + \pi \right) + i \sin \left(-\frac{\pi}{8} + \pi \right) \right] \approx -1.55 + 2.77i$$

$$w_3 = 3 \left[\cos \left(-\frac{\pi}{8} + \frac{3\pi}{2} \right) + i \sin \left(-\frac{\pi}{8} + \frac{3\pi}{2} \right) \right] \approx -2.77 - 1.55i$$



Part 2:

Given $p(z)$ with complex coefficients has root w and $p(\bar{w}) \neq 0$

In other words, we want $p(w) = 0$ and $p(\bar{w}) \neq 0$

Using the most simple polynomial, $p(z) = z - w$ and letting $w = 3e^{i\frac{-\pi}{8}}$ we have

$$p(z) = z - 3e^{i\frac{-\pi}{8}}$$

$$\begin{aligned} p(w) &= w - w \\ &= 3e^{i\frac{-\pi}{8}} - 3e^{i\frac{-\pi}{8}} \\ &= 0 \end{aligned}$$

$$\begin{aligned} p(\bar{w}) &= \bar{w} - 3e^{i\frac{-\pi}{8}} \\ &= 3e^{-i\frac{\pi}{8}} - 3e^{i\frac{-\pi}{8}} \\ &= 3 \left[\cos \left(\frac{\pi}{8} \right) - i \sin \left(\frac{\pi}{8} \right) - \left(\cos \left(\frac{\pi}{8} \right) + i \sin \left(\frac{\pi}{8} \right) \right) \right] \\ &= 3 \left[\cos \left(\frac{\pi}{8} \right) - i \sin \left(\frac{\pi}{8} \right) - \cos \left(\frac{\pi}{8} \right) - i \sin \left(\frac{\pi}{8} \right) \right] \\ &= 3 \left[-2i \sin \left(\frac{\pi}{8} \right) \right] \\ &= -6i \sin \left(\frac{\pi}{8} \right) \\ &\approx -2.3i \neq 0 \end{aligned}$$

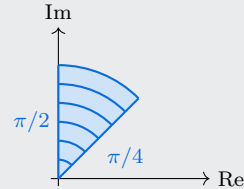
Example 3.5: Determine and sketch the image under the map $w = e^z$, $\{z \in \mathbb{C} : \pi/4 \leq \text{Im}(z) \leq \pi/2\}$

$$\begin{aligned} w &= e^z = e^{x+iy} \\ &= e^x e^{iy} \\ &= e^x [\cos(y) + i \sin(y)] \end{aligned}$$

Recall the polar form of a complex number $z = |z|[\cos(\theta) + i \sin(\theta)]$

We see, e^x acts as the radius, and is always positive, and $[\cos(y) + i \sin(y)]$ acts draws out a section of the unit circle, thus the mapping $w = e^z$ sends the set to:

$$\left\{ w \in \mathbb{C} : |w| > 0, \frac{\pi}{4} \leq \arg(w) \leq \frac{\pi}{2} \right\}$$

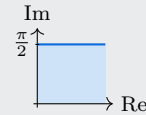


Example 3.6: Determine and sketch the region $w = \text{Log}(z)$, $\{z : |z| > 1, 0 \leq \text{Arg}(z) \leq \pi/2\}$

$$w = \text{Log}(z) = \ln |z| + i \text{Arg}(z) = u + iv$$

Note that $|z| > 1$ implies $\ln |z| > 0$ Thus:

$$\left\{ w = u + iv \in \mathbb{C} : u > 0, 0 \leq v \leq \frac{\pi}{2} \right\}$$



Example 3.7: Find where the function is 0 : $\cos(z) = \frac{e^{iz} + e^{-iz}}{2}$

We want $\cos(z) = \frac{e^{iz} + e^{-iz}}{2} = 0$, some basic algebra gives us:

$$\cos(z) = \frac{e^{iz} + e^{-iz}}{2} = 0$$

$$e^{iz} + e^{-iz} = 0$$

$$e^{iz} = -e^{-iz}$$

$$e^{iz} \cdot e^{iz} = -e^{-iz} \cdot e^{iz}$$

$$e^{2iz} = -e^0$$

$$e^{2iz} = -1$$

Multiply both sides by e^{iz}

$$e^a \cdot e^b = e^{a+b}$$

Recall:

$$-1 = \cos(\pi + 2\pi k) + i \sin(\pi + 2\pi k) = e^{i(\pi + 2\pi k)}$$

Thus

$$e^{2iz} = e^{i(\pi + 2\pi k)}$$

$$2iz = i(\pi + 2\pi k)$$

$$2z = \pi + 2\pi k$$

$$z = \frac{\pi}{2} + \pi k$$

Taking the natural log of both sides

Divide by 2

Divide by i

Therefore, the zeros of $\cos(z)$ are:

$$z = \frac{\pi}{2} + \pi k, \quad k \in \mathbb{Z}$$

Example 3.8: Calculate the principal value $\text{Log}(z)$ of $z = -\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}i$ and prove e^z is the inverse function of $\text{Log}(z)$

Part 1.

Given $z = -\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}i$:

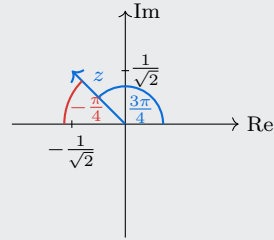
$$\ln |z| = \sqrt{\left(\frac{1}{\sqrt{2}}\right)^2 + \left(\frac{1}{\sqrt{2}}\right)^2} = 1$$

and

$$\begin{aligned}\text{Arg}(z) &= \tan^{-1}(-1) \\ &= -\tan^{-1}(1) \\ &= -\frac{\pi}{4} \Rightarrow \frac{3\pi}{4}\end{aligned}$$

Therefore

$$\text{Log}(z) = \ln |z| + i\text{Arg}(z) = i\frac{3\pi}{4}$$



Part 2: We need to show that (a) $e^{\text{Log}(z)} = z$ and (b) $\text{Log}(e^z) = z$

(a) Let $z = |z|e^{i\theta}$, $|z| > 0$ and $\theta = \text{Arg}(z)$

$$\begin{aligned}\text{Log}(z) &= \ln |z| + i\theta \\ e^{\text{Log}(z)} &= e^{\ln |z| + i\theta} \\ &= e^{\ln |z|} \cdot e^{i\theta} \\ &= |z| \cdot e^{i\theta} \\ e^{\text{Log}(z)} &= z\end{aligned}$$

Exponentiate both sides

Exponentiation rules

(b) Let $z = x + iy$, $y \in [-\pi, \pi]$

$$\begin{aligned}e^z &= e^{x+iy} \\ &= e^x \cdot e^{iy} \\ \text{Log}(e^z) &= \ln |e^x \cdot e^{iy}| \\ &= \ln |e^x| + \ln |e^{iy}| \\ &= x + iy \\ \text{Log}(e^z) &= z\end{aligned}$$

Take log of both sides

$$\log(a \cdot b) = \log(a) + \log(b)$$

Example 3.9: Define the complex conjugate (\bar{w}) and prove if w is a zero of a polynomial $p(z) = a_0 + a_1z + \dots + a_nz^n$ then \bar{w} is also a zero of $p(z)$

Definition: For a complex number $w = a + bi$ the complex conjugate of w is defined as $\bar{w} = a - bi$ (with $a, b \in \mathbb{R}$ and $i = \sqrt{-1}$)

This has several properties:

$$\begin{aligned}\overline{z + w} &= \bar{z} + \bar{w} \\ \overline{zw} &= \bar{z} \cdot \bar{w} \\ \overline{(w^n)} &= (\bar{w})^n\end{aligned}$$

Proof: If w is zero of a polynomial $p(z) = a_0 + a_1z + \dots + a_nz^n$ then $p(w) = 0$

$$\text{Assume } p(w) = a_0 + a_1w + \dots + a_nw^n = 0$$

$$\text{Take the conjugate of both sides } \overline{p(w)} = \bar{0} = 0$$

$$\text{Evaluate } p(\bar{w}) = a_0 + a_1\bar{w} + \dots + a_n\bar{w}^n$$

$$= a_0 + a_1\bar{w} + \dots + a_n\overline{w^n}$$

$$= \overline{a_0} + \overline{a_1w} + \dots + \overline{a_nw^n}$$

$$= \overline{a_0 + a_1w + \dots + a_nw^n}$$

$$= \overline{p(w)} = 0$$

Thus, since we assumed $p(w) = 0$:

$$p(\bar{w}) = \overline{p(w)} = 0$$

Example 3.10: Define the complex exponential function e^z and prove Eulers Formula $e^{i\theta} = \cos(\theta) + i \sin \theta$

Definition : For any $z \in \mathbb{C}$, e^z is defined by its power series:

$$e^z = \sum_{n=0}^{\infty} \frac{z^n}{n!}$$

The series converges for all $z \in \mathbb{C}$ and has the following properties:

$$e^{z_1+z_2} = e^{z_1} \cdot e^{z_2}$$

$$e^z \cdot e^{-z} = 1$$

Proof of Eulers Formula

$$\text{Eulers Formula } e^{i\theta} = \cos(\theta) + i \sin(\theta)$$

$$\begin{aligned} e^{i\theta} &= \sum_{n=0}^{\infty} \frac{(i\theta)^n}{n!} && \text{Substitute } z = i\theta \\ &= \sum_{n=0}^{\infty} \frac{(i\theta)^{2n}}{(2n)!} + \sum_{n=0}^{\infty} \frac{(i\theta)^{2n+1}}{(2n+1)!} && \text{Split into even and odd powers} \\ &= \sum_{n=0}^{\infty} \frac{(i)^{2n}(\theta)^{2n}}{(2n)!} + \sum_{n=0}^{\infty} \frac{(i)^{2n+1}(\theta)^{2n+1}}{(2n+1)!} && \text{Seperate powers} \end{aligned}$$

We note that:

$$\begin{aligned} i^{2n} &= (i^2)^n = (-1)^n \\ i^{2n+1} &= i \cdot i^{2n} = i(-1)^n \end{aligned}$$

Thus:

$$\begin{aligned} e^{i\theta} &= \sum_{n=0}^{\infty} \frac{(-1)^n(\theta)^{2n}}{(2n)!} + \sum_{n=0}^{\infty} \frac{i(-1)^n(\theta)^{2n+1}}{(2n+1)!} \\ &= \sum_{n=0}^{\infty} \frac{(-1)^n(\theta)^{2n}}{(2n)!} + i \sum_{n=0}^{\infty} \frac{(-1)^n(\theta)^{2n+1}}{(2n+1)!} \\ &:= \cos(\theta) + i \sin(\theta) \end{aligned}$$

4 Worked Examples - Q2

Example 4.1: Determine the image of the line $f(z) = \frac{1}{z}$ $\{z \in \mathbb{C} : \operatorname{Re}(z) = 2\}$

Let:

$$w = f(z) = \frac{1}{z}$$

Then we have:

$$\begin{aligned} w &= \frac{1}{z}, \text{ so that } zw = 1 \Rightarrow z = \frac{1}{w}, \\ z &= \frac{1}{u+iv} = \frac{u-iv}{(u+iv)(u-iv)} = \frac{u-iv}{u^2+v^2} = \frac{u}{u^2+v^2} - i \frac{v}{u^2+v^2} \end{aligned}$$

We note that: $\operatorname{Re}(z) = \frac{u}{u^2+v^2} = a$

$$u = a(u^2 + v^2) \Rightarrow \frac{1}{a}u = u^2 + v^2 \Rightarrow u^2 - \frac{1}{a}u + v^2 = 0$$

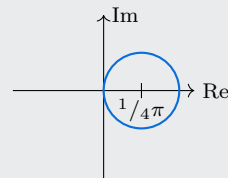
Completing the square in u :

$$\left(u^2 - \frac{1}{2a}\right)^2 - \frac{1}{4a^2} + av^2 = 0 \Rightarrow \left(u^2 - \frac{1}{2a}\right)^2 + av^2 = \frac{1}{4a^2}$$

Letting $a = 2$:

$$\left(u^2 - \frac{1}{4}\right)^2 + 4v^2 = \frac{1}{16}$$

Thus the image is sphere with radius $\frac{1}{4}$ and centre $(\frac{1}{4}, 0)$



Example 4.2: Determine the image of the line $f(z) = \frac{1}{z}$ $\{z \in \mathbb{C} : \operatorname{Re}(z) = 1\}$

Let:

$$w = f(z) = \frac{1}{z}$$

Then we have:

$$w = \frac{1}{z}, \quad \text{so that } zw = 1 \Rightarrow z = \frac{1}{w},$$

$$z = \frac{1}{u + iv} = \frac{u - iv}{(u + iv)(u - iv)} = \frac{u - iv}{u^2 + v^2} = \frac{u}{u^2 + v^2} - i \frac{v}{u^2 + v^2}$$

We note that: $\operatorname{Re}(z) = \frac{u}{u^2 + v^2} = a$

$$u = a(u^2 + v^2) \Rightarrow \frac{1}{a}u = u^2 + v^2 \Rightarrow u^2 - \frac{1}{a}u + v^2 = 0$$

Completing the square in u :

$$\left(u^2 - \frac{1}{2a}\right)^2 - \frac{1}{4a^2} + av^2 = 0 \Rightarrow \left(u^2 - \frac{1}{2a}\right)^2 + av^2 = \frac{1}{4a^2}$$

Letting $a = 1$:

$$\left(u^2 - \frac{1}{2}\right)^2 + v^2 = \frac{1}{4}$$

Thus the image is sphere with radius $\frac{1}{2}$ and centre $(\frac{1}{2}, 0)$

