EASTERN UNIVERSITY, SRI LANKA

THIRD EXAMINATION IN SCIENCE, (2004/2005)

(January/February, 2005)

FIRST SEMESTER

PROPER & REPEAT

MT 302 - COMPLEX ANALYSIS

Answer all questions | Time allowed: 3 Hours

Q1. (a) Let $A \subseteq \mathbb{C}$ be an open set and let $f : A \to \mathbb{C}$. Define what is meant by f being **analytic** at $z_0 \in A$. [20]

(b) Let the function $f(z) = u(x, y) + iv(x, y)$ be defined throughout some ϵ neighbourhood of a point $z_0 = x_0 + iy_0$. Suppose that the first-order partial derivatives of the functions $u(x, y)$ and $v(x, y)$ with respect to x and y exist everywhere in that neighbourhood and that they are continuous at (x_0, y_0). Prove that if those partial derivatives satify the Cauchy-Riemann equations, that is, $u_x = v_y$ and $u_y = -v_x$ at (x_0, y_0) then the derivative $f'(z_0)$ exists. [50]

(c) Verify the analyticity of the following function

$$f(z) = z\,e^{-z}, \quad z = x + iy,$$

in the complex plane. [30]

Q2. (a) (i) Define what is meant by a **path** $\gamma : [\alpha, \beta] \to \mathbb{C}$. [10]

(ii) For a path γ and a continuous function $f : \gamma \to \mathbb{C}$, define $\int_\gamma f(z)\, dz$. [10]

(b) Let $a \in \mathbb{C}$, $r > 0$, and $n \in \mathbb{Z}$. Show that

$$\int_{C(a;\, r)} (z-a)^n\, dz = \begin{cases} 0, & n \neq -1, \\ 2\pi i, & n = -1 \end{cases}$$

where $C(a;r)$ denotes a positively oriented circle with centre a and radius r. [30]

(State **without proof** any results you may assume).

(c) State the **Cauchy's Integral Formula**. [20]

By using the **Cauchy's Integral Formula**, compute the following integrals:

(i) $\displaystyle\int_{C(0;3)} \frac{e^{zt}}{z^2+1}\, dz, \qquad t > 0;$ [15]

(ii) $\displaystyle\int_{C(0;2)} \frac{\cos z}{(z^3+9z)}\, dz.$ [15]

Q3. (a) State the **Mean Value Property for Analytic Functions.** [10]

(b) (i) Define what is meant by the function $f : \mathbb{C} \to \mathbb{C}$ being **entire**. [10]

(ii) Prove **Liouville's Theorem**: If f is entire and

$$\frac{\max\{|f(t)| : |t| = r\}}{r} \to 0, \quad \text{as } r \to \infty,$$

then f is constant. [30]

(State any results you use without proof)

(c) Prove the **Maximum-Modulus Theorm**: Let f be analytic in an open connected set A. Let γ be a simple closed path that is contained, together with its inside, in A. Let

$$M := \sup_{z \in \gamma} |f(z)|.$$

If there exists z_0 inside γ such that $|f(z_0)| = M$, then f is constant throughout A. Consequently, if f is not constant in A, then

$$|f(z)| < M, \quad \forall\, z \text{ inside } \gamma.$$

[50]

(State any theorem you use without proof)

Q4. (a) Let $\delta > 0$ and let $f : D^*(z_0; \delta) \to \mathbb{C}$, where $D^*(z_0; \delta) := \{z : 0 < |z - z_0| < \delta\}$. Define what is meant by

(i) f having a singularity at z_0;

(ii) the order of f at z_0;

(iii) f having a pole or zero at z_0 of order m;

(iv) f having a simple pole or simple zero at z_0.

[40]

(b) Prove that

$$ord(f; z_0) = m$$

if and only if

$$f(z) = (z - z_0)^m\, g(z), \quad z \in D^*(z_0; \delta),$$

for some $\delta > 0$, where g is analytic in $D(z_0; \delta)$ and $g(z_0) \neq 0$.

[60]

Q5. (a) Prove that if f has a simple pole at z_0, then

$$Res(f; z_0) = \lim_{z \to z_0} (z - z_0) f(z_0).$$

[30]

(b) Let f be analytic in $\{z : Im(z) \geq 0\}$, except possibly for finitely many singularities, none on the real axis. Suppose there exist $M, R > 0$ and $\alpha > 1$ such that

$$|f(z)| \leq \frac{M}{|z|^\alpha}, \quad |z| \geq R \text{ with } Im(z) \geq 0.$$

Then prove that

$$I := \int_{-\infty}^{\infty} f(x)\,dx$$

converges (exists) and

$$I = 2\pi i \times \text{Sum of Residues of } f \text{ in the upper half plane.}$$

[50]

Hence evaluate the integral

$$\int_{-\infty}^{\infty} \frac{x^2}{(x^2+1)^2}\,dx.$$

[20]

(You may assume without proof the Residue Theoerem).

Q6. (a) State the **Principle of the Argument Theorem.** [20]

(b) Prove **Rouche's Theorem**: Let γ be a simple closed path in an open starset A. Suppose that

(i) f, g are analytic in A except for finitely many poles, none lying on γ.

(ii) f and $f+g$ have finitely many zeros in A.

(iii) $|g(z)| < |f(z)|, \quad z \in \gamma$. Then

$$ZP(f+g;\gamma) = ZP(f;\gamma)$$

where $ZP(f+g;\gamma)$ and $ZP(f;\gamma)$ denote the number of zeros − number of poles inside γ of $f+g$ and f respectively, counted as many times as its order. [40]

(c) State the **Fundamental theorem of Algebra.** [20]

(d) Prove that all 5 zeros of $P(z) = z^5 + 3z^3 + 1$ lie in $|z| < 2$. [20]