

6. Answer **either** (a), (b), (c) **or** (d):

(a) Prove that if a series of complex numbers converges, then the n th term converges to zero as n tends to infinity. 3

(b) Test the convergence of the sequence

$$z_n = \frac{1}{n^3} + i \quad (n = 1, 2, \dots) \quad 3$$

(c) Find Maclaurin's series for the entire function $f(z) = I^z$. 4

Or

(d) Suppose that a function f is analytic throughout a disc $|z - z_0| < R_0$ centred at z_0 and with radius R_0 . Then prove that $f(z)$ has a power series representation

$$f(z) = \sum_{n=0}^{\infty} a_n (z - z_0)^n \quad (|z - z_0| < R_0)$$

$$\text{where } a_n = \frac{f^{(n)}(z_0)}{n!} \quad (n = 0, 1, 2, \dots)$$

2024

MATHEMATICS

(Honours Core)

Paper : MAT-HC-6016

New Syllabus

(Riemann Integration and Metric Spaces)

Full Marks : 80

Time : Three hours

Old Syllabus

(Complex Analysis)

Full Marks : 60

Time : Three hours

The figures in the margin indicate full marks for the questions.

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New Syllabus

(Riemann Integration and Metric Spaces)

Full Marks : 80

Time : Three hours

1. Answer the following as directed : $1 \times 10 = 10$
- (a) Let $f : [a, b] \rightarrow R$ be a bounded function and P, Q are partitions of $[a, b]$. If Q is a refinement of P , then
- $L(f, Q) \leq L(f, P)$
 - $U(f, P) \leq U(f, Q)$
 - $U(f) \leq L(f)$
 - $L(f) \leq U(f)$
- (Choose the correct option)
- (b) Find the value of $\int_0^{\infty} e^{-x} dx$.
- (c) Show that $\Gamma(1) = 1$.
- (d) Define Cauchy sequence in a metric space.
- (e) State whether the following statement is true **or** false :
"Each subset of a discrete metric space is open."

(f) If the mapping $d : R^2 \times R^2 \rightarrow R$ is defined as $d((x_1, y_1), (x_2, y_2)) = |x_1 - x_2|$, then which one of the following statements is true ?

- d is the usual metric on R^2
 - d is uniform metric on R^2
 - d is a pseudo metric on R^2
 - None of the above statements is true
- (g) Which of the following statements is true ?
- In a metric space countable union of open sets is open
 - In a metric space finite union of closed sets is closed
 - A non-empty subset of a metric space is closed if and only if its complement is open
 - None of the above statements is true
- (h) When is a metric space said to be connected.

(i) State whether the following statement is true **or** false :

"Image of an open set under a continuous function is open."

(j) Under what condition the metric spaces (X, d_X) and (Y, d_Y) are said to be equivalent ?

2. Answer the following questions : $2 \times 5 = 10$

(a) Let $u, v : [a, b] \rightarrow R$ be differentiable and u', v' are integrable on $[a, b]$. Then show that

$$\int_a^b u(x)v'(x)dx = [u(x)v(x)]_a^b - \int_a^b u'(x)v(x)dx.$$

(b) Show that a subset F of a metric space (X, d) is closed if and only if $\bar{F} = F$.

(c) Let (Y, d_Y) be a subspace of a metric space (X, d_X) and $S_X(z, r)$ and $S_Y(z, r)$ are open balls with center at $z \in Y$ and radius r in the metric space (X, d_X) and (Y, d_Y) respectively.

Prove that $S_Y(z, r) = S_X(z, r) \cap Y$.

(c) Let (X, d) be a metric space and the function $d^* : X \times X \rightarrow R$ is defined as

$$d^*(x, y) = \frac{d(x, y)}{1 + d(x, y)}, \forall x, y \in X$$

Show that (X, d^*) is a bounded metric space.

(d) Let Y be a non-empty subset of the metric space (X, d) . Prove that the subspace (Y, d_Y) is complete if and only if Y is closed on (X, d) .

(e) Show that composition of two uniformly continuous functions is also uniformly continuous.

(f) Show that a metric space (X, d) is disconnected if and only if there exists a continuous function of (X, d) onto the discrete two element space (X_0, d_0) , i.e.,

$X_0 = \{0, 1\}$ and d_0 is the discrete metric on X_0 .

(d) Show that the image of a Cauchy sequence under uniformly continuous function is again a Cauchy sequence.

(e) Show that a contraction mapping on a metric space is uniformly continuous.

3. Answer **any four** questions : $5 \times 4 = 20$

(a) Show that a bounded function $f : [a, b] \rightarrow R$ is integrable if and only if for each $\varepsilon > 0$, there exists a partition P of $[a, b]$ such that $U(f, P) - L(f, P) < \varepsilon$.

(b) Let g be a continuous function on the closed interval $[a, b]$ and the function f be continuously differentiable on $[a, b]$. Further if f' does not change sign on $[a, b]$, then show that there exists $c \in [a, b]$ such that

$$\int_a^b f(x)g(x)dx = f(a) \int_a^c g(x)dx + f(b) \int_c^b g(x)dx.$$

4. Answer the following questions : $10 \times 4 = 40$

(a) Let f be a function on an interval J with n th derivative $f^{(n)}$ continuous on J . If $a, b \in J$, then show that

$$f(b) = f(a) + \frac{f'(a)}{1!}(b-a) + \dots + \frac{f^{(n-1)}(a)}{(n-1)!}(b-a)^{n-1} + R_n$$

$$\text{where, } R_n = \int_a^b \frac{(b-t)^{n-1}}{(n-1)!} f^{(n)}(t) dt$$

Or

Let $f : [0, 1] \rightarrow R$ be continuous and

$$c_i \in \left[\frac{i-1}{n}, \frac{i}{n} \right], n \in N.$$

Then show that

$$\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n f(c_i) = \int_0^1 f(x) dx.$$

Hence show that

$$\lim_{n \rightarrow \infty} \sum_{r=1}^n \frac{r}{r^2 + n^2} = \log \sqrt{2}. \quad 5+5=10$$

(b) Let l_p ($p \geq 1$) be the set of all sequences of real numbers such that if

$$x = \{x_n\}_{n \geq 1} \in l_p, \text{ then } \sum_{i=1}^{\infty} |x_i|^p < \infty.$$

Prove that the function $d : l_p \times l_p \rightarrow R$

$$\text{defined by } d(x, y) = \left\{ \sum_{n=1}^{\infty} |x_n - y_n|^p \right\}^{\frac{1}{p}}$$

is a metric on l_p . Also show that l_p is a complete metric space. 4+6=10

Or

(i) Let (X, d) be a metric space and $\{x_n\}_{n \geq 1}, \{y_n\}_{n \geq 1}$ be two sequences in X such that $x_n \rightarrow x$ and $y_n \rightarrow y$ as $n \rightarrow \infty$. Then show that $d(x_n, y_n) \rightarrow d(x, y)$ as $n \rightarrow \infty$. 4

(ii) Let (X, d) be a metric space and Y a subspace of X . Let Z be a subset of Y . Then show that Z is closed in Y if and only if there exists a closed set $F \subseteq X$ such that $Z = F \cap Y$. 6

(c) What are meant by contraction mapping and fixed point of a contraction mapping in a metric space? If $T : X \rightarrow X$ is a contraction mapping on a complete metric space, then show that T has a unique fixed point. (1+1)+8=10

Or

If (X, d) be a metric space, then show that the following statements are equivalent :

- (i) (X, d) is disconnected.
- (ii) There exist two non-empty disjoint subsets A and B , both open in X , such that $X = A \cup B$.
- (iii) There exist two non-empty disjoint subsets A and B , both closed in X , such that $X = A \cup B$.
- (iv) There exists a proper subset of X that is both open and closed in X .

(d) (i) Let $f : [a, b] \rightarrow R$ be integrable and

$$F(x) = \int_a^x f(t) dt; \quad x \in [a, b]. \text{ Show}$$

that F is continuous on $[a, b]$. Also show that F is differentiable at $x \in [a, b]$ if f is continuous at $x \in [a, b]$ and $F'(x) = f(x)$. 7

(ii) Let (X, d) be a metric space and $\rho : X \times X \rightarrow R$ be defined by

$$\rho(x, y) = \frac{d(x, y)}{1 + d(x, y)}; \quad x, y \in X.$$

Show that d and ρ are equivalent metrics. 3

Or

(iii) Show that a subset G of a metric space (X, d) is open if and only if it is the union of all open balls contained in G . 5

(iv) Give example, with justification, of a homeomorphism from a metric space onto another metric space which is not an isometry. 5

Old Syllabus

Full Marks : 60

(Complex Analysis)

Time : Three hours

1. Answer the following as directed : 1×7=7

(a) Determine the accumulation point of the set $z_n = \frac{i}{n}$ ($n = 1, 2, 3, \dots$)

(b) Describe the domain of $f(z) = \frac{z}{z + \bar{z}}$.

(c) Define an entire function.

(d) Determine the singular points of

$$f(z) = \frac{2z+1}{z(z^2+1)}$$

(e) The value of $\log e$ is

(i) 1

(ii) $1 + 2n\pi i$

(iii) $2n\pi i$

(iv) 0

(Choose the correct option)

- (f) $\lim_{n \rightarrow \infty} \left(-2 + i \frac{(-1)^n}{n^2} \right)$ is equal to
- (i) 0 (ii) -2
- (iii) $-2 + i$ (iv) limit does not exist
(Choose the correct option)
- (g) The power expression for $\cos z$ is
- (i) $\frac{e^z + e^{-z}}{2}$ (ii) $\frac{e^{iz} + e^{-iz}}{2}$
- (iii) $\frac{e^{iz} + e^{-iz}}{2i}$ (iv) $\frac{e^z - e^{-z}}{2}$
(Choose the correct option)

2. Answer the following questions: $2 \times 4 = 8$

- (a) Sketch the set $|z - 1 + i| \leq 1$
- (b) Prove that $f'(z)$ exists every where for the function $f(z) = iz + 2$.
- (c) If $f(z) = \frac{z}{z}$, prove that $\lim_{z \rightarrow 0} f(z)$ does not exist.
- (d) Evaluate $\int_1^2 \left(\frac{1}{t} - i \right) dt$.

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3. Answer **any three** questions from the following: $5 \times 3 = 15$

- (a) (i) Show that if e^z is real, then $Im z = n\pi$ ($n = 0, \pm 1, \pm 2, \dots$) 3
- (ii) Show that $\exp(2 \pm 3\pi i) = -e^2$. 2

- (b) Suppose that $f(z) = u(x, y) + iv(x, y)$, where $z = x + iy$ and $z_0 = x_0 + iy_0$, $w_0 = u_0 + iv_0$. Then prove that

$$\lim_{z \rightarrow z_0} f(z) = w_0 \text{ if}$$

$$\lim_{(x,y) \rightarrow (x_0, y_0)} u(x, y) = u_0 \text{ and}$$

$$\lim_{(x,y) \rightarrow (x_0, y_0)} v(x, y) = v_0$$

- (c) Show that $f'(z)$ exists everywhere, when $f(z) = e^z$.

- (d) Evaluate $\int_C \frac{dz}{z}$, where C is the top half of the circle $|z| = 1$ from $z = 1$ to $z = -1$.

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Contd.

- (e) Let C denote the positively oriented boundary of the square whose sides lie along the lines $x = \pm 2$ and $y = \pm 2$. Applying Cauchy's integral formula, evaluate $\int_C \frac{e^{-z} dz}{z - (\pi i/2)}$.

4. Answer **either** (a) or (b) and (c):
- (a) Suppose that $f(z) = u(x, y) + iv(x, y)$ and that $f'(z)$ exists at a point $z_0 = x_0 + iy_0$. Prove that the first order partial derivatives of u and v must exist at (x_0, y_0) and they must satisfy the Cauchy-Riemann equations $u_x = v_y$ and $u_y = -v_x$ there.
- Also show that $f'(z) = u_x + iv_x = v_y - iv_y$ where partial derivatives are to be evaluated at (x_0, y_0) . 10

Or

- (b) If z_0 and w_0 are points in the z -plane and w -plane respectively, then prove that $\lim_{z \rightarrow z_0} f(z) = \infty$ if and only if

$$\lim_{z \rightarrow z_0} \frac{1}{f(z)} = 0$$

Hence show that $\lim_{z \rightarrow -1} \frac{iz + 3}{z + 1} = \infty$

$4 + 2 = 6$

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- (c) If $w = f(z) = \bar{z}$, examine whether $\frac{dw}{dz}$ exists or not. 4

5. Answer **either** (a) or (b):

- (a) Let C denote a contour of length L and suppose that a function $f(z)$ is piecewise continuous on C . If M is a non-negative constant such that $|f(z)| \leq M$ for all points z on C at which $f(z)$ is defined, then prove that

$$\left| \int_C f(z) dz \right| \leq ML$$

Hence show that

$$\left| \int_C \frac{dz}{z^2 - 1} \right| \leq \pi/3, \text{ where } C \text{ is the arc of}$$

the semicircle $|z| = 2$ from $z = 2$ to $z = 2i$ that lies in the first quadrant. 10

Or

- (b) State and prove Liouville's theorem.

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Contd.