

## UNIT-I PARTIAL DIFFERENTIAL EQUATIONS

### PART-A

**1. Eliminate the arbitrary constants a & b from  $z = (x^2 + a)(y^2 + b)$**

**Answer:**

$$z = (x^2 + a)(y^2 + b)$$

$$\text{Diff partially w.r.to } x \text{ \& } y \text{ here } p = \frac{\partial z}{\partial x} \text{ \& } q = \frac{\partial z}{\partial y}$$

$$\begin{aligned} p &= 2x(y^2 + b) ; q = (x^2 + a) 2y \\ \Rightarrow (y^2 + b) &= p/2x ; (x^2 + a) = q/2y \\ z &= (p/2x)(q/2y) \\ \Rightarrow 4xyz &= pq \end{aligned}$$

**2. Form the PDE by eliminating the arbitrary function from  $z = f(xy)$**

**Answer:**

$$z = f(xy) , \text{ Diff partially w.r.to } x \text{ \& } y \text{ here } p = \frac{\partial z}{\partial x} \text{ \& } q = \frac{\partial z}{\partial y}$$

$$\begin{aligned} p &= f'(xy) \cdot y \quad q = f'(xy) \cdot x \\ p/q &= y/x \Rightarrow px - qy = 0 \end{aligned}$$

**3. Form the PDE by eliminating the constants a and b from  $z = ax^n + by^n$**

**Answer:**

$$z = ax^n + by^n ,$$

$$\text{Diff. w.r. to } x \text{ and } y \text{ here } p = \frac{\partial z}{\partial x} \text{ \& } q = \frac{\partial z}{\partial y}$$

$$p = nax^{n-1} ; q = nby^{n-1}$$

$$a = \frac{p}{nx^{n-1}} ; b = \frac{q}{ny^{n-1}}$$

$$\therefore z = \frac{p}{nx^{n-1}} x^n + \frac{q}{ny^{n-1}} y^n$$

$$\Rightarrow nz = px + qy$$

**4. Find the complete integral of  $p + q = pq$**

**Answer:**

$$\text{Put } p = a, q = b ,$$

$$p + q = pq \Rightarrow a + b = ab$$

$$\Rightarrow b - ab = -a \Rightarrow b = \frac{-a}{1-a} = \frac{a}{a-1}$$

$$\text{The complete integral is } z = ax + \frac{a}{a-1} y + c$$

**5. Find the solution of  $\sqrt{p} + \sqrt{q} = 1$**

**Answer:**

$$z = ax + by + c \quad \text{----(1) is the required solution}$$

$$\text{given } \sqrt{p} + \sqrt{q} = 1 \quad \text{----(2)}$$

$$\text{put } p = a, q = b \text{ in (2)}$$

$$\sqrt{a} + \sqrt{b} = 1 \Rightarrow \sqrt{b} = 1 - \sqrt{a} \Rightarrow b = (1 - \sqrt{a})^2$$

$$\therefore z = ax + (1 - \sqrt{a})^2 y + c$$

6. Find the General solution of  $p \tan x + q \tan y = \tan z$ .

**Answer:**

$$\begin{aligned} \frac{dx}{\tan x} &= \frac{dy}{\tan y} = \frac{dz}{\tan z} \\ \Rightarrow \cot x dx &= \cot y dy = \cot z dz \\ \text{take } \int \cot x dx &= \int \cot y dy & \int \cot y dy &= \int \cot z dz \\ \Rightarrow \log \sin x &= \log \sin y + \log c_1 & \Rightarrow \log \sin y &= \log \sin z + \log c_2 \\ \Rightarrow c_1 &= \frac{\sin x}{\sin y} & \Rightarrow c_2 &= \frac{\sin y}{\sin z} \end{aligned}$$

$$\therefore \Phi \left[ \frac{\sin x}{\sin y}, \frac{\sin y}{\sin z} \right] = 0$$

7. Eliminate the arbitrary function  $f$  from  $z = f(x^2 - y^2)$  and form the PDE.

**Answer:**

$$\begin{aligned} z &= f(x^2 - y^2) \\ p &= f'(x^2 - y^2) \cdot 2x; \quad q = f'(x^2 - y^2) \cdot (-2y) \\ \frac{p}{q} &= \frac{2x}{-2y} \Rightarrow py + qx = 0 \end{aligned}$$

8. Find the equation of the plane whose centre lie on the z-axis

**Answer:** General form of the sphere equation is  $x^2 + y^2 + z - c^2 = r^2$  (1)

Where 'r' is a constant. From (1)

$$2x + 2(z - c) p = 0 \quad (2)$$

$$2y + 2(z - c) q = 0 \quad (3)$$

From (2) and (3)

$$\frac{x}{p} = -\frac{y}{q}, \quad \text{That is} \quad py - qx = 0 \quad \text{which is a required PDE.}$$

9. Eliminate the arbitrary constants  $z = ax + by + \sqrt{a^2 + b^2}$  and form the PDE.

**Answer:**  $z = ax + by + \sqrt{a^2 + b^2}$

$$p = a; q = b$$

$$\therefore z = px + qy + \sqrt{p^2 + q^2}$$

10. Find the singular integral of  $z = px + qy + pq$

**Answer:** The complete solution is  $z = ax + by + ab$

$$\frac{\partial z}{\partial a} = 0 = x + b; \quad \frac{\partial z}{\partial b} = 0 = y + a$$

$$\Rightarrow b = -x; \quad a = -y$$

$$\therefore z = (-y)x + (-x)y + (-y)(-x)$$

$$= -xy - xy + xy$$

$$= -xy$$

$$\therefore xy + z = 0$$

### 11. Find the general solution of $px+qy=z$

**Answer:**

The auxiliary equation is  $\frac{dx}{x} = \frac{dy}{y} = \frac{dz}{z}$

From  $\frac{dx}{x} = \frac{dy}{y}$  Integrating we get  $\log x = \log y + \log c$

on simplifying  $\frac{x}{y} = c_1$ .

$$\frac{dy}{y} = \frac{dz}{z} \Rightarrow \frac{y}{z} = c_2$$

Therefore  $\phi\left(\frac{x}{y}, \frac{y}{z}\right) = 0$  is general solution.

### 12. Find the general solution of $px^2+qy^2=z^2$

**Answer:**

The auxiliary equation is  $\frac{dx}{x^2} = \frac{dy}{y^2} = \frac{dz}{z^2}$

From  $\frac{dx}{x^2} = \frac{dy}{y^2}$  Integrating we get  $\frac{1}{y} - \frac{1}{x} = c_1$

Also  $\frac{dy}{y^2} = \frac{dz}{z^2}$  Integrating we get  $\frac{1}{z} - \frac{1}{y} = c_2$

Therefore  $\phi\left(\frac{1}{y} - \frac{1}{x}, \frac{1}{z} - \frac{1}{y}\right) = 0$  is general solution.

### 13. Solve $D^2 - 2DD' - 3D'^2 z = 0$

**Answer:**

Auxiliary equation is  $m^2 - 2m - 3 = 0$ ,

$$m-3 \quad m+1 = 0, \quad m = -1, m = 3$$

The solution is  $z = f_1 y - x + f_2 y + 3x$

### 14. Solve $D^2 - 4DD' + 3D'^2 z = e^{x+y}$

**Answer:** Auxiliary equation is  $m^2 - 4m + 3 = 0$ ,  $m-3 \quad m-1 = 0$ ,  $m = 1, m = 3$

The CF is  $CF = f_1 y + x + f_2 y + 3x$

$$PI = \frac{1}{D^2 - 4DD' + 3D'^2} e^{x+y} \quad \text{Put } D = 1, D' = -1 \text{ Denominator} = 0.$$

$$PI = \frac{x}{2D - 4D'} e^{x+y} = -\frac{xe^{x+y}}{2}$$

**Z = CF + PI**

$$z = f_1 y + x + f_2 y + 3x - \frac{xe^{x+y}}{2}$$

### 15. Solve. $D^2 - 3DD' - 4D'^2 z = e^{x-y}$

**Answer:**

Auxiliary equation is  $m^2 - 3m - 4 = 0$ ,  $m-4 \quad m+1 = 0$ ,  $m = 4, m = -1$

C.F is  $= f_1(y + 4x) + f_2(y - x)$

$$PI = \frac{1}{D^2 - 3DD' - 4D'^2} e^{x+y} = \frac{1}{1-3-4} e^{x+y} = \frac{1}{-6} e^{x+y}$$

**16. Find P.I**  $D^2 - 4DD' + 4D'^2 \quad z = e^{2x-y}$

**Answer:**

$$PI = \frac{1}{D^2 - 4DD' + 4D'^2} e^{2x-y}$$

Put  $D = 2, D' = -1$   $PI = \frac{1}{D - 2D'}^2 e^{2x-y} = \frac{1}{2+2}^2 e^{2x-y} = \frac{e^{2x-y}}{16}$

PART-B

1. Solve  $x^2 \quad y - z \quad p + y^2 \quad z - x \quad q = z^2 \quad x - y$
2. Solve  $x \quad z^2 - y^2 \quad p + y \quad x^2 - z^2 \quad q = z \quad y^2 - x^2$
3. Solve  $mz - ny \quad \frac{\partial z}{\partial x} + nx - lz \quad \frac{\partial z}{\partial y} = ly - mx$
4. Solve  $3z - 4y \quad p + 4x - 2z \quad q = 2y - 3x$
5. Solve  $x^2 - y^2 - z^2 \quad p + 2xyq = 2xz$
6. Solve  $y^2 + z^2 - x^2 \quad p - 2xyq + 2zx = 0$
7. Solve  $y - z \quad p + z - x \quad q = x - y$
8. Solve  $y + z \quad p + z + x \quad q = x + y$
9. Solve  $D^2 - 3DD' + 2D'^2 = e^{3x-2y} + \sin(3x + 2y)$
10. Solve  $\frac{\partial^2 z}{\partial x^2} - \frac{\partial^2 z}{\partial x \partial y} = \cos x \cos 2y$
11. Solve  $D^2 + DD' - 6D'^2 \quad z = y \cos x$
12. Solve  $D^2 - DD' - 30D'^2 \quad z = xy + e^{6x+y}$
13. Solve  $D^2 - 6DD' + 5D'^2 \quad z = e^x \sinh y + xy$
14. Solve  $D^2 - 4DD' + 4D'^2 \quad z = e^{2x+y}$
15. Solve  $D^3 - D^2 D' - DD'^2 - D'^3 \quad z = e^{2x+y} + \cos(x + y)$
16. Solve  $z = px + qy + \sqrt{1 + p^2 + q^2}$
17. Solve  $z = px + qy - p^2 q^2$
18. Solve  $z^2 = 1 + p^2 + q^2$
19. Solve  $z^2 (p^2 x^2 + q^2) = 1$
20. Solve (i)  $z (p^2 - q^2) = x^2 - y^2$  (ii)  $z^2 (p^2 + q^2) = x^2 + y^2$

**PART-A**

**1. Define R.M.S value.**

If let  $f(x)$  be a function defined in the interval  $(a, b)$ , then the R.M.S value of

$$f(x) \text{ is defined by } \bar{y} = \sqrt{\frac{1}{b-a} \int_a^b f(x)^2 dx}$$

**2. State Parseval's Theorem.**

Let  $f(x)$  be periodic function with period  $2l$  defined in the interval  $(c, c+2l)$ .

$$\frac{1}{2l} \int_c^{c+2l} f(x)^2 dx = \frac{a_o^2}{4} + \frac{1}{2} \sum_{n=1}^{\infty} a_n^2 + b_n^2 \quad \text{Where } a_o, a_n \text{ \& } b_n \text{ are Fourier constants}$$

**3. Define periodic function with example.**

If a function  $f(x)$  satisfies the condition that  $f(x + T) = f(x)$ , then we say  $f(x)$  is a periodic function with the period  $T$ .

**Example:-**

- i)  $\sin x, \cos x$  are periodic function with period  $2\pi$
- ii)  $\tan x$  is are periodic function with period  $\pi$ .

**4. State Dirichlets condition.**

- (i)  $f(x)$  is single valued periodic and well defined except possibly at a Finite number of points.
- (ii)  $f(x)$  has at most a finite number of finite discontinuous and no infinite Discontinuous.
- (iii)  $f(x)$  has at most a finite number of maxima and minima.

**5. State Euler's formula.**

**Answer:**

In  $(c, c+2l)$

$$f(x) = \frac{a_o}{2} + \sum a_n \cos nx + b_n \sin nx$$

$$\text{where } a_o = \frac{1}{\pi} \int_c^{c+2l} f(x) dx$$

$$a_n = \frac{1}{\pi} \int_c^{c+2l} f(x) \cos nx dx$$

$$b_n = \frac{1}{\pi} \int_c^{c+2l} f(x) \sin nx dx$$

**6. Write Fourier constant formula for  $f(x)$  in the interval  $(0, 2\pi)$**

**Answer:**

$$a_o = \frac{1}{\pi} \int_0^{2\pi} f(x) dx$$

$$a_n = \frac{1}{\pi} \int_0^{2\pi} f(x) \cos nx dx$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} f(x) \sin nx dx$$

**7. In the Fourier expansion of**

$$f(x) = \begin{cases} 1 + \frac{2x}{\pi}, & -\pi < x < 0 \\ 1 - \frac{2x}{\pi}, & 0 < x < \pi \end{cases} \quad \text{in } (-\pi, \pi), \text{ find the value of } b_n.$$

**Answer:**

Since  $f(-x) = f(x)$  then  $f(x)$  is an even function. Hence  $b_n = 0$

**8. If  $f(x) = x^3$  in  $-\pi < x < \pi$ , find the constant term of its Fourier series.**

**Answer:**

$$\text{Given } f(x) = x^3 \Rightarrow f(-x) = (-x)^3 = -x^3 = -f(x)$$

Hence  $f(x)$  is an odd function

The required constant term of the Fourier series  $= a_0 = 0$

**9. What are the constant term  $a_0$  and the coefficient of  $\cos nx$  in the Fourier Expansion  $f(x) = x - x^3$  in  $-\pi < x < \pi$**

**Answer:**

$$\text{Given } f(x) = x - x^3 \Rightarrow f(-x) = -x - (-x)^3 = -[x - x^3] = -f(x)$$

Hence  $f(x)$  is an odd function

The required constant term of the Fourier series  $= a_0 = 0$

**10. Find the value of  $a_0$  for  $f(x) = 1 + x + x^2$  in  $(0, 2\pi)$**

**Answer:**

$$\begin{aligned} a_0 &= \frac{1}{\pi} \int_0^{2\pi} f(x) dx \\ &= \frac{1}{\pi} \int_0^{2\pi} (1 + x + x^2) dx = \frac{1}{\pi} \left[ x + \frac{x^2}{2} + \frac{x^3}{3} \right]_0^{2\pi} \\ &= \frac{1}{\pi} \left[ 2\pi + \frac{4\pi^2}{2} + \frac{8\pi^3}{3} \right] = \left[ 2 + 2\pi + \frac{8\pi^2}{3} \right] \end{aligned}$$

**11. (i) Find  $b_n$  in the expansion of  $x^2$  as a Fourier series in  $(-\pi, \pi)$**

**(ii) Find  $b_n$  in the expansion of  $x \sin x$  as a Fourier series in  $(-\pi, \pi)$**

**Answer:**

$$(i) \text{ Given } f(x) = x^2 \Rightarrow f(-x) = x^2 = f(x)$$

Hence  $f(x)$  is an even function

In the Fourier series  $b_n = 0$

$$(ii) \text{ Given } f(x) = x \sin x \Rightarrow f(-x) = (-x) \sin(-x) = x \sin x = f(x)$$

Hence  $f(x)$  is an even function

In the Fourier series  $b_n = 0$

**12. Obtain the sine series for  $f(x) = \begin{cases} x & 0 \leq x \leq l/2 \\ l-x & l/2 \leq x \leq l \end{cases}$**

$$\text{Given } f(x) = \begin{cases} x & 0 \leq x \leq l/2 \\ l-x & l/2 \leq x \leq l \end{cases}$$

**Answer:**

$$\text{Given } f(x) = \begin{cases} x & 0 \leq x \leq l/2 \\ l-x & l/2 \leq x \leq l \end{cases}$$

$$\text{Fourier sine series is } f(x) = \sum b_n \sin \frac{nx}{l}$$

$$\begin{aligned}
b_n &= \frac{2}{l} \int_0^l f(x) \sin \frac{nx}{l} dx \\
&= \frac{2}{l} \left\{ \int_0^{l/2} x \sin \frac{nx}{l} dx + \int_{l/2}^l (l-x) \sin \frac{nx}{l} dx \right\} \\
&= \frac{2}{l} \left\{ \left[ lx \left( \frac{-\cos \frac{nx}{l}}{n} \right) - (1)l^2 \left( \frac{-\sin \frac{nx}{l}}{n^2} \right) \right]_0^{l/2} + \left[ l(l-x) \left( \frac{-\cos \frac{nx}{l}}{n} \right) - l^2(-1) \left( \frac{-\sin \frac{nx}{l}}{n^2} \right) \right]_{l/2}^l \right\} \\
&= \frac{2}{l} \left[ \frac{-l^2 \cos n\pi/2}{2n\pi} + \frac{l^2 \sin n\pi/2}{\pi^2 n^2} + \frac{l^2 \cos nl/2}{2n\pi} + \frac{l^2 \sin n\pi/2}{\pi^2 n^2} \right] \\
&= \frac{2}{l} \left[ \frac{2l^2 \sin n\pi/2}{\pi^2 n^2} \right] = \frac{4l \sin n\pi/2}{\pi^2 n^2}
\end{aligned}$$

Fourier series is  $f(x) = \frac{4l}{\pi^2} \sum_{n=1}^{\infty} \frac{\sin n\pi/2}{n^2} \sin \frac{n\pi x}{l}$

**13. If  $f(x)$  is odd function in  $-l, l$ . What are the value of  $a_0$  &  $a_n$**

**Answer:**

If  $f(x)$  is an odd function,  $a_0 = 0, a_n = 0$

**14. In the Expansion  $f(x) = |x|$  as a Fourier series in  $(-\pi, \pi)$  find the value of  $a_0$**

**Answer:**

Given  $f(x) = |x| \Rightarrow f(-x) = |-x| = |x| = f(x)$

Hence  $f(x)$  is an even function

$$\therefore a_0 = \frac{2}{\pi} \int_0^{\pi} x dx = \frac{2}{\pi} \left[ \frac{x^2}{2} \right]_0^{\pi} = \frac{2}{\pi} \left[ \frac{\pi^2}{2} \right] = \pi$$

**15. Find half range cosine series of  $f(x) = x$ , in  $0 < x < \pi$**

**Answer:**  $a_0 = \frac{2}{\pi} \int_0^{\pi} x dx = \frac{2}{\pi} \left[ \frac{x^2}{2} \right]_0^{\pi} = \frac{2}{\pi} \left[ \frac{\pi^2}{2} \right] = \pi$

$$\begin{aligned}
a_n &= \frac{2}{\pi} \int_0^{\pi} x \sin nx dx = \frac{1}{\pi} \left[ x \left( \frac{-\cos nx}{n} \right) - (1) \left( \frac{-\sin nx}{n^2} \right) \right]_0^{\pi} \\
&= \frac{1}{\pi} \left[ \frac{-\pi \cos n\pi}{n} - 0 - 0 \right] = \frac{-(-1)^n}{n} = \frac{-1^{n+1}}{n}
\end{aligned}$$

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos nx$$

Fourier series is  $= \frac{\pi}{2} + \sum_{n=1}^{\infty} \frac{-1^{n+1}}{n} \cos nx$

**16. Find the RMS value of  $f(x) = x^2$ ,  $0 < x < 1$**

**Answer:**

Given  $f(x) = x^2$

R.M.S value

$$\begin{aligned}\bar{y} &= \sqrt{\frac{1}{l} \int_0^l f(x)^2 dx} = \sqrt{\frac{1}{1/2} \int_0^1 x^2^2 dx} \\ &= \sqrt{2 \left[ \frac{x^5}{5} \right]_0^1} = \sqrt{\frac{2}{5}}\end{aligned}$$

**PART-B**

1. Expand  $f(x) = \begin{cases} x & (0, \pi) \\ 2\pi - x & (\pi, 2\pi) \end{cases}$  as Fourier series and hence deduce that  $\frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \dots = \frac{\pi^2}{8}$

2. Find the Fourier series for  $f(x) = x^2$  in  $(-\pi, \pi)$  and also prove that

$$(i) \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \dots = \frac{\pi^2}{6} \quad (ii) \frac{1}{1^2} - \frac{1}{2^2} + \frac{1}{3^2} - \dots = \frac{\pi^2}{12}$$

3. Expand  $f(x) = |\cos x|$  as Fourier series in  $(-\pi, \pi)$ .

4. Find cosine series for  $f(x) = x^2$  in  $(-\pi, \pi)$  use Parseval's identity to

$$\text{Show that } \frac{1}{1^4} + \frac{1}{2^4} + \frac{1}{3^4} + \dots = \frac{\pi^4}{90}$$

5. Expand  $f(x) = x \sin x$  as a Fourier series in  $(0, 2\pi)$

6. Expand  $f(x) = |x|$  as a Fourier series in  $(-\pi, \pi)$  and deduce to  $\frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \dots = \frac{\pi^2}{8}$

7. If  $f(x) = \begin{cases} 0 & (-\pi, 0) \\ \sin x & (0, \pi) \end{cases}$  Find the Fourier series and hence deduce that

$$\frac{1}{1.3} - \frac{1}{3.5} + \frac{1}{5.7} - \dots = \frac{\pi - 2}{4}$$

8. Find the Fourier series up to second harmonic

X	0	1	2	3	4	5
Y	9	18	24	28	26	20

9. Find the Fourier series up to third harmonic

X	0	$\pi/3$	$2\pi/3$	$\pi$	$4\pi/3$	$5\pi/3$	$2\pi$
F(x)	10	14	19	17	15	12	10

10. Find the Fourier expansion of  $f(x) = (\pi - x)^2$  in  $(0, 2\pi)$  and

$$\text{Hence deduce that } \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \dots = \frac{\pi^2}{6}$$

11. Find a Fourier series to represent  $f(x) = 2x - x^2$  with period 3 in the range  $(0, 3)$

12. Find the Fourier series of  $f(x) = e^x$  in  $(-\pi, \pi)$ .



13. Find the Fourier series for  $f(x) = \begin{cases} 1 & \text{in } (0, \pi) \\ 2 & \text{in } (\pi, 2\pi) \end{cases}$  and hence s.t  $\frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \dots = \frac{\pi^2}{8}$

14. Find the half range sine series for  $f(x) = x(\pi - x)$  in the interval  $(0, \pi)$  and

deduce that  $\frac{1}{1^3} - \frac{1}{3^3} + \frac{1}{5^3} - \dots$

15. Obtain the half range cosine series for  $f(x) = x - 1^2$  in  $(0, 1)$

and also deduce that  $\frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \dots = \frac{\pi^2}{6}$

16. Find the Fourier series for  $f(x) = x^2$  in  $(-\pi, \pi)$  and also prove that  $1 + \frac{1}{4^4} + \frac{1}{2^4} + \dots = \frac{\pi^4}{90}$

### UNIT-III APPLICATIONS OF PARTIAL DIFFERENTIAL EQUATIONS

#### PART-A

1. Classify the Partial Differential Equation i)  $\frac{\partial^2 u}{\partial x^2} = \frac{\partial^2 u}{\partial y^2}$

**Answer:**

$$\frac{\partial^2 u}{\partial x^2} = \frac{\partial^2 u}{\partial y^2} \text{ here } A=1, B=0, \& C=-1$$

$B^2 - 4AC = 0 - 4(1)(-1) = 4 > 0$ . The Partial Differential Equation is hyperbolic.

2. Classify the Partial Differential Equation  $\frac{\partial^2 u}{\partial x \partial y} = \left(\frac{\partial u}{\partial y}\right)\left(\frac{\partial u}{\partial x}\right) + xy$

**Answer:**

$$\frac{\partial^2 u}{\partial x \partial y} = \left(\frac{\partial u}{\partial y}\right)\left(\frac{\partial u}{\partial x}\right) + xy \text{ here } A=0, B=1, \& C=0$$

$B^2 - 4AC = 1 - 4(0)(0) = 1 > 0$ . The Partial Differential Equation is hyperbolic.

3. Classify the following second order Partial Differential equation  $\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial x}\right)^2$

**Answer:**  $\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial x}\right)^2$  here  $A=1, B=0, \& C=1$

$B^2 - 4AC = 0 - 4(1)(1) = -4 < 0$ . The Partial Differential Equation is Elliptic.

4. Classify the following second order Partial Differential equation

$$4\frac{\partial^2 u}{\partial x^2} + 4\frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 u}{\partial y^2} - 6\left(\frac{\partial u}{\partial x}\right) - 8\left(\frac{\partial u}{\partial y}\right) = 0$$

**Answer:**

$$4\frac{\partial^2 u}{\partial x^2} + 4\frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 u}{\partial y^2} - 6\left(\frac{\partial u}{\partial x}\right) - 8\left(\frac{\partial u}{\partial y}\right) = 0$$

here  $A=4, B=4, \& C=1$

$B^2 - 4AC = 16 - 4(4)(1) = 0$ . The Partial Differential Equation is Parabolic.

5. Classify the following second order Partial Differential equation

$$\text{i) } y^2 u_{xx} - 2xy u_{xy} + x^2 u_{yy} + 2u_x - 3u = 0$$

$$\text{ii) } y^2 u_{xx} + u_{yy} + u_x^2 + u_y^2 + 7 = 0$$

**Answer:**

i) Parabolic ii) Hyperbolic (If  $y = 0$ ) iii) Elliptic (If  $y$  may be +ve or -ve)

6. In the wave equation  $\frac{\partial^2 y}{\partial t^2} = c^2 \frac{\partial^2 y}{\partial x^2}$  what does  $c^2$  stands for?

**Answer:**

$$\frac{\partial^2 y}{\partial t^2} = c^2 \frac{\partial^2 y}{\partial x^2} \quad \text{here } c^2 = \frac{T}{m} \quad \text{T-Tension and m- Mass}$$

7. In one dimensional heat equation  $u_t = \alpha^2 u_{xx}$  what does  $\alpha^2$  stands for?

**Answer:-**  $\frac{\partial u}{\partial t} = \alpha^2 \frac{\partial^2 u}{\partial x^2}$

$$\alpha^2 = \frac{k}{\rho c} \quad \text{is called diffusivity of the substance}$$

Where k – Thermal conductivity

$\rho$  - Density

c – Specific heat

8. State any two laws which are assumed to derive one dimensional heat equation

**Answer:**

i) Heat flows from higher to lower temp

ii) The rate at which heat flows across any area is proportional to the area and to the temperature gradient normal to the curve. This constant of proportionality is known as the conductivity of the material. It is known as Fourier law of heat conduction

9. A tightly stretched string of length  $2\ell$  is fastened at both ends. The midpoint of the string is displaced to a distance 'b' and released from rest in this position. Write the initial conditions.

**Answer:**

(i)  $y(0, t) = 0$

(ii)  $y(2\ell, t) = 0$

(iii)  $\left( \frac{\partial y}{\partial t} \right)_{t=0} = 0$

(iv)  $y(x, 0) = \begin{cases} \frac{b}{\ell} x & 0 \leq x \leq \ell \\ \frac{b}{\ell} (2\ell - x) & \ell \leq x \leq 2\ell \end{cases}$

10. What are the possible solutions of one dimensional Wave equation?

The possible solutions are

**Answer:**

$$y(x, t) = (A e^{\lambda x} + B e^{-\lambda x}) (C e^{\lambda at} + D e^{-\lambda at})$$

$$y(x, t) = (A \cos \lambda x + B \sin \lambda x) (C \cos \lambda at + D \sin \lambda at)$$

$$y(x, t) = (Ax + B) (Ct + D)$$

11. What are the possible solutions of one dimensional head flow equation?

**Answer:**

The possible solutions are

$$u(x, t) = (A e^{\lambda x} + B e^{-\lambda x}) C e^{-\alpha^2 \lambda^2 t}$$

$$u(x, t) = (A \cos \lambda x + B \sin \lambda x) C e^{-\alpha^2 \lambda^2 t}$$

$$u(x, t) = (Ax + B) C$$

12. State Fourier law of heat conduction

**Answer:**  $Q = -kA \frac{\partial u}{\partial x}$

(the rate at which heat flows across an area A at a distance from one end of a bar is proportional to temperature gradient)

Q=Quantity of heat flowing

k – Thermal conductivity, A=area of cross section ;  $\frac{\partial u}{\partial x}$  =Temperature gradient

### 13. What are the possible solutions of two dimensional head flow equation?

**Answer:**

The possible solutions are

$$u(x, y) = (Ae^{\lambda x} + Be^{-\lambda x})(C \cos \lambda y + D \sin \lambda y)$$

$$u(x, y) = (A \cos \lambda x + B \sin \lambda x)(Ce^{\lambda y} + De^{-\lambda y})$$

$$u(x, y) = (Ax + B)(Cy + D)$$

**14. The steady state temperature distribution is considered in a square plate with sides  $x = 0$ ,  $y = 0$ ,  $x = a$  and  $y = a$ . The edge  $y = 0$  is kept at a constant temperature  $T$  and the three edges are insulated. The same state is continued subsequently. Express the problem mathematically.**

**Answer:**

$$U(0, y) = 0, U(a, y) = 0, U(x, a) = 0, U(x, 0) = T.$$

### **PART-B**

1. A tightly stretched string with fixed end points  $x = 0$  and  $x = l$  is initially at rest in its equilibrium position. If it is set vibrating giving each point a velocity  $3x(l-x)$ . Find the displacement.
2. A string is stretched and fastened to two points and apart. Motion is started by displacing the string into the form  $y = K(lx-x^2)$  from which it is released at time  $t = 0$ . Find the displacement at any point of the string.
3. A string of length  $2l$  is fastened at both ends. The midpoint of string is taken to a height  $b$  and then released from rest in that position. Find the displacement of the string.
4. A tightly stretched string with fixed end points  $x = 0$  and  $x = l$  is initially at rest in its position given by  $y(x, 0) = y_0 \sin^3 \frac{\pi x}{l}$ . If it is released from rest find the displacement.

5. A string is stretched between two fixed points at a distance  $2l$  apart and points of the string are

$$\text{given initial velocities where } V = \begin{cases} \frac{cx}{l} & 0 < x < l \\ \frac{c}{l}(2l-x) & l < x < 2l \end{cases}. \quad \text{Find the displacement.}$$

6. Derive all possible solution of one dimensional wave equation. Derive all possible solution of one dimensional heat equation. Derive all possible solution of two dimensional heat equations.
7. A rod 30 cm long has its end A and B kept at  $20^\circ\text{C}$  and  $80^\circ\text{C}$ , respectively until steady state condition prevails. The temperature at each end is then reduced to  $0^\circ\text{C}$  and kept so. Find the resulting temperature  $u(x, t)$  taking  $x = 0$ .
8. A rectangular plate with insulated surface is 8 cm wide so long compared to its width that it is a bar 10 cm long, with insulated sides has its end A & B kept at  $20^\circ\text{C}$  and  $40^\circ\text{C}$  respectively until the steady state condition prevails. The temperature at A is suddenly raised to  $50^\circ\text{C}$  and B is lowered to  $10^\circ\text{C}$ . Find the subsequent temperature function  $u(x, t)$ .
9. A rectangular plate with insulated surface is 8 cm wide and so long compared to its width that it may be considered as an infinite plate. If the temperature along short edge  $y = 0$  is

$$u(x, 0) = 100 \sin \frac{\pi x}{8}, \quad 0 < x < 8 \quad \text{While two edges } x = 0 \text{ and } x = 8 \text{ as well as the other short edges are kept at } 0^\circ\text{C. Find the steady state temperature.}$$

10. A rectangular plate with insulated surface is 10 cm wide so long compared to its width that it may be considered as an infinite plate. If the temperature along short edge  $y = 0$  is given by

$$u = \begin{cases} 20x & 0 \leq x \leq 5 \\ 20(10-x) & 5 \leq x \leq 10 \end{cases} \quad \text{and all other three edges are kept at } 0^\circ\text{C. Find the steady state temperature at any point of the plate.}$$

## UNIT-IV FOURIER TRANSFORMS

### PART-A

#### 1. State Fourier Integral Theorem.

Answer:

If  $f(x)$  is piece wise continuously differentiable and absolutely on  $-\infty, \infty$  then,

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(t) e^{i(x-t)s} dt ds.$$

#### 2. State and prove Modulation theorem.

$$F[f(x) \cos ax] = \frac{1}{2} [F(s+a) + F(s-a)]$$

**Proof:**

$$\begin{aligned} F[f(x) \cos ax] &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) \cos ax e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) \left( \frac{e^{iax} + e^{-iax}}{2} \right) e^{isx} dx \\ &= \frac{1}{2} \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{i(s+a)x} dx + \frac{1}{2} \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{i(s-a)x} dx \\ &= \frac{1}{2} F(s+a) + \frac{1}{2} F(s-a) \end{aligned}$$

$$F[f(x) \cos ax] = \frac{1}{2} [F(s+a) + F(s-a)]$$

#### 3. State Parseval's Identity.

Answer:

If  $F(s)$  is a Fourier transform of  $f(x)$ , then

$$\int_{-\infty}^{\infty} |F(s)|^2 ds = \int_{-\infty}^{\infty} |f(x)|^2 dx$$

#### 4. State Convolution theorem.

Answer:

The Fourier transforms of Convolution of  $f(x)$  and  $g(x)$  is the product of their Fourier transforms.

$$F[f * g] = F(s) G(s)$$

#### 5. State and prove Change of scale of property.

Answer:

If  $F(s) = F[f(x)]$ , then  $F[f(ax)] = \frac{1}{a} F(s/a)$

$$\begin{aligned} F[f(ax)] &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(ax) e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t) e^{i \frac{s}{a} t} \frac{dt}{a}; \quad \text{where } t = ax, \quad F[f(ax)] = \frac{1}{a} F(s/a) \end{aligned}$$

6. Prove that if  $F[f(x)] = F(s)$  then  $F[x^n f(x)] = (-i)^n \frac{d^n}{ds^n} F(s)$

**Answer:**

$$F[s] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{isx} dx, \text{ Diff w.r.t } s \text{ 'n' times}$$

$$\begin{aligned} \frac{d^n}{ds^n} F[s] &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) (ix)^n e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) (i)^n (x)^n e^{isx} dx \end{aligned}$$

$$\frac{1}{(i)^n} \frac{d^n}{ds^n} F[s] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} (x)^n f(x) e^{isx} dx$$

$$(-i)^n \frac{d^n}{ds^n} F[s] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} (x)^n f(x) e^{isx} dx$$

$$F[x^n f(x)] = (-i)^n \frac{d^n}{ds^n} F[s]$$

7. Solve for  $f(x)$  from the integral equation  $\int_0^{\infty} f(x) \cos sx dx = e^{-s}$

**Answer:**

$$\int_0^{\infty} f(x) \cos sx dx = e^{-s}$$

$$F_c[f(x)] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \cos sx dx$$

$$F_c[f(x)] = \sqrt{\frac{2}{\pi}} e^{-s}$$

$$f(x) = \sqrt{\frac{2}{\pi}} \int_0^{\infty} F_c[f(x)] \cos sx ds$$

$$= \sqrt{\frac{2}{\pi}} \int_0^{\infty} \sqrt{\frac{2}{\pi}} e^{-s} \cos sx ds$$

$$= \frac{2}{\pi} \int_0^{\infty} e^{-s} \cos sx ds = \frac{2}{\pi} \left[ \frac{1}{x^2 + 1} \right]$$

$$\left| \int_0^{\infty} e^{-ax} \cos bx dx = \frac{a}{a^2 + b^2} \right.$$

$\therefore a = 1, b = x$

8. Find the complex Fourier Transform of  $f(x) = \begin{cases} 1 & |x| < a \\ 0 & |x| > a > 0 \end{cases}$

**Answer:**  $F[f(x)] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{isx} dx$   $\because |x| < a; -a < x < a$

$$\begin{aligned} F[f(x)] &= \frac{1}{\sqrt{2\pi}} \int_{-a}^a 1 e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-a}^a (\cos sx + i \sin sx) dx \\ &= \frac{2}{\sqrt{2\pi}} \int_0^a (\cos sx) dx = \frac{2}{\sqrt{2\pi}} \left( \frac{\sin sx}{s} \right)_0^a \\ &= \sqrt{\frac{2}{\pi}} \left( \frac{\sin as}{s} \right) \end{aligned}$$

[Use even and odd property second term become zero]

9. Find the complex Fourier Transform of  $f(x) = \begin{cases} x & |x| < a \\ 0 & |x| > a > 0 \end{cases}$

**Answer:**

$$\begin{aligned} F[f(x)] &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-a}^a x e^{isx} dx \quad \because |x| < a; -a < x < a \\ &= \frac{1}{\sqrt{2\pi}} \int_{-a}^a x (\cos sx + i \sin sx) dx \\ &= \frac{2}{\sqrt{2\pi}} \int_0^a (x(i \sin sx)) dx = \frac{2i}{\sqrt{2\pi}} \left[ x \left( \frac{-\cos sx}{s} \right) - (1) \left( \frac{-\sin sx}{s^2} \right) \right]_0^a \\ &= i \sqrt{\frac{2}{\pi}} \left[ \frac{-as \cos as + \sin as}{s^2} \right] \end{aligned}$$

[Use even and odd property first term become zero]

10. Write Fourier Transform pair.

**Answer:** If  $f(x)$  is defined in  $-\infty, \infty$ , then its Fourier transform is defined as

$$F(s) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{isx} dx$$

If  $F(s)$  is an Fourier transform of  $f(x)$ , then at every point of Continuity of  $f(x)$ , we have

$$f(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} F(s) e^{-isx} ds.$$

**11. Find the Fourier cosine Transform of  $f(x) = e^{-x}$**

**Answer:**

$$F_c[f(x)] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \cos sx \, dx$$

$$F_c[e^{-x}] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} e^{-x} \cos sx \, dx \quad \because \int_0^{\infty} e^{-ax} \cos bx \, dx = \frac{a}{a^2 + b^2}$$

$$F_c[e^{-x}] = \sqrt{\frac{2}{\pi}} \frac{1}{s^2 + 1}$$

**12. Find the Fourier Transform of  $f(x) = \begin{cases} e^{imx}, & a < x < b \\ 0, & \text{otherwise} \end{cases}$**

**Answer:**

$$\begin{aligned} F[f(x)] &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(x) e^{isx} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_a^b e^{imx} e^{isx} dx = \frac{1}{\sqrt{2\pi}} \int_a^b e^{i(m+s)x} dx \\ &= \frac{1}{\sqrt{2\pi}} \left[ \frac{e^{i(m+s)x}}{i(m+s)} \right]_a^b = \frac{1}{\sqrt{2\pi}} \frac{1}{i(m+s)} [e^{i(m+s)b} - e^{i(m+s)a}] \end{aligned}$$

**13. Find the Fourier sine Transform of  $\frac{1}{x}$ .**

**Answer:**

$$\begin{aligned} F_s[f(x)] &= \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \sin sx \, dx \\ &= \sqrt{\frac{2}{\pi}} \int_0^{\infty} \frac{\sin sx}{x} \, dx = \sqrt{\frac{2}{\pi}} \frac{\pi}{2} \end{aligned}$$

$$F_s\left[\frac{1}{x}\right] = \sqrt{\frac{\pi}{2}}$$

**14. Find the Fourier sine transform of  $e^{-x}$**

$$F_s[f(x)] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \sin sx \, dx$$

$$F_s[e^{-x}] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} e^{-x} \sin sx \, dx \quad \because \int_0^{\infty} e^{-ax} \sin bx \, dx = \frac{b}{a^2 + b^2}$$

$$F_s[e^{-x}] = \sqrt{\frac{2}{\pi}} \frac{s}{s^2 + 1}$$

**15. Find the Fourier cosine transform of  $e^{-2x} + 2e^{-x}$**

**Answer:**

$$F_c[f(x)] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \cos sx \, dx$$

$$F_c[e^{-2x} + 2e^{-x}] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} e^{-2x} + 2e^{-x} \cos sx \, dx$$

$$= \sqrt{\frac{2}{\pi}} \left\{ \int_0^{\infty} e^{-2x} \cos sx \, dx + 2 \int_0^{\infty} e^{-x} \cos sx \, dx \right\}$$

$$= \sqrt{\frac{2}{\pi}} \left\{ \frac{2}{s^2 + 4} + 2 \frac{1}{s^2 + 1} \right\} = 2\sqrt{\frac{2}{\pi}} \left\{ \frac{1}{s^2 + 4} + \frac{1}{s^2 + 1} \right\}$$

**16. Find the Fourier sine transform of  $f(x) = \begin{cases} 1, & 0 \leq x \leq 1 \\ 0 & x > 1 \end{cases}$**

$$F_s[f(x)] = \sqrt{\frac{2}{\pi}} \int_0^{\infty} f(x) \sin sx \, dx$$

$$F_s[f(x)] = \sqrt{\frac{2}{\pi}} \left\{ \int_0^1 f(x) \sin sx \, dx + \int_1^{\infty} f(x) \sin sx \, dx \right\}$$

$$= \sqrt{\frac{2}{\pi}} \left\{ \int_0^1 1 \sin sx \, dx + 0 \right\} = \sqrt{\frac{2}{\pi}} \left[ -\frac{\cos sx}{s} \right]_0^1$$

$$= \sqrt{\frac{2}{\pi}} \left[ \frac{1 - \cos s}{s} \right]$$

### **PART-B**

1. Find the Fourier Transform of  $f(x) = \begin{cases} 1-x^2 & \text{if } |x| < 1 \\ 0 & \text{if } |x| > 1 \end{cases}$  and hence

deduce that (i)  $\int_0^{\infty} \left( \frac{x \cos x - \sin x}{x^3} \right) \cos \left( \frac{x}{2} \right) dx = -\frac{3\pi}{16}$  (ii)  $\int_0^{\infty} \left( \frac{\sin x - x \cos x}{x^3} \right)^2 dx = \frac{\pi}{15}$

2. Find the Fourier Transform of  $f(x) = \begin{cases} a^2 - x^2 & |x| < a \\ 0 & |x| > a > 0 \end{cases}$ . hence S.T  $\int_0^{\infty} \left( \frac{\sin x - x \cos x}{x^3} \right) dx = \frac{\pi}{4}$

3. Find the Fourier Transform of  $f(x) = \begin{cases} 1 & \text{if } |x| < a \\ 0 & \text{if } |x| > a \end{cases}$  and hence evaluate

i)  $\int_0^{\infty} \frac{\sin x}{x} dx$     ii)  $\int_0^{\infty} \left( \frac{\sin x}{x} \right)^2 dx$

4. Find Fourier Transform of  $f(x) = \begin{cases} 1-|x| & \text{if } |x| < 1 \\ 0 & \text{if } |x| > 1 \end{cases}$  and hence evaluate

i)  $\int_0^{\infty} \left( \frac{\sin x}{x} \right)^2 dx$     ii)  $\int_0^{\infty} \left( \frac{\sin x}{x} \right)^4 dx$



5. Evaluate i)  $\int_0^{\infty} \frac{x^2}{x^2 + a^2} dx$  ii)  $\int_0^{\infty} \frac{dx}{x^2 + a^2}$

6. Evaluate i)  $\int_0^{\infty} \frac{x^2}{x^2 + a^2} dx$  ii)  $\int_0^{\infty} \frac{dx}{x^2 + a^2}$

7. Evaluate (a)  $\int_0^{\infty} \frac{dx}{x^2 + 1}$   $\int_0^{\infty} \frac{dx}{x^2 + 4}$  (b)  $\int_0^{\infty} \frac{t^2 dt}{t^2 + 4}$   $\int_0^{\infty} \frac{t^2 dt}{t^2 + 9}$

8. (i) Find the Fourier sine transform of  $f(x) = \begin{cases} \sin x; & \text{when } 0 < x < \pi \\ 0 & ; \text{when } x > \pi \end{cases}$

(ii) Find the Fourier cosine transform of  $f(x) = \begin{cases} \cos x; & \text{when } 0 < x < a \\ 0 & ; \text{when } x > a \end{cases}$

9. (i) Show that Fourier transform  $e^{-\frac{x^2}{2}}$  is  $e^{-\frac{s^2}{2}}$

(ii) Obtain Fourier cosine Transform of  $e^{-a^2 x^2}$  and hence find Fourier sine Transform  $x e^{-a^2 x^2}$

10. (i) Solve for  $f(x)$  from the integral equation  $\int_0^{\infty} f(x) \cos \alpha x dx = e^{-\alpha}$

(ii) Solve for  $f(x)$  from the integral equation  $\int_0^{\infty} f(x) \sin tx dx = \begin{cases} 1 & , 0 \leq t < 1 \\ 2 & , 1 \leq t < 2 \\ 0 & , t \geq 2 \end{cases}$

11. Find Fourier sine Transform of  $e^{-x}$ ,  $x > 0$  and hence deduce that  $\int_0^{\infty} \frac{x \sin x}{1 + x^2} dx$

12. (i) Find  $F_s \{ x e^{-ax} \}$  &  $F_c \{ x e^{-ax} \}$  (ii) Find  $F_s \left( \frac{e^{-ax}}{x} \right)$  &  $F_c \left( \frac{e^{-ax}}{x} \right)$

## UNIT-V Z- TRANSFORMS

### PART-A

#### 1. Define Z transform

##### Answer:

Let  $\{f(n)\}$  be a sequence defined for  $n = 0, 1, 2, \dots$  and  $f(n) = 0$  for  $n < 0$  then its Z – Transform is defined as

$$Z \{ f(n) \} = F(z) = \sum_{n=-\infty}^{\infty} f(n) z^{-n} \quad (\text{Two sided } z \text{ transform})$$

$$Z \{ f(n) \} = F(z) = \sum_{n=0}^{\infty} f(n) z^{-n} \quad (\text{One sided } z \text{ transform})$$

#### 2. Find the Z Transform of 1

##### Answer:

$$Z \left[ f(n) \right] = \sum_{n=0}^{\infty} f(n) z^{-n}$$

$$Z \{ 1 \} = \sum_{n=0}^{\infty} (1) z^{-n} = 1 + z^{-1} + z^{-2} + \dots = 1 - z^{-1}^{-1}$$

$$= \left( 1 - \frac{1}{z} \right)^{-1} = \left( \frac{z-1}{z} \right)^{-1} = \left( \frac{z}{z-1} \right) \quad Z \{ 1 \} = \left( \frac{z}{z-1} \right)$$

### 3. Find the Z Transform of n

**Answer:**

$$\begin{aligned} Z[f(n)] &= \sum_{n=0}^{\infty} f(n) z^{-n} \\ Z(n) &= \sum_{n=0}^{\infty} n z^{-n} \\ &= \sum_{n=0}^{\infty} n z^{-n} = 0 + z^{-1} + 2z^{-2} + 3z^{-3} + \dots \\ &= z^{-1} \left[ 1 - z^{-1} \right]^{-2} = \frac{1}{z} \left[ 1 - \frac{1}{z} \right]^{-2} = \frac{1}{z} \left[ \frac{z}{z-1} \right]^2 \\ &= \frac{z}{(z-1)^2} \end{aligned}$$

### 4. Find the Z Transform of n<sup>2</sup>.

**Answer:**  $Z(n^2) = Z(n \cdot n) = -z \frac{d}{dz} Z(n)$ , by the property,

$$= -z \frac{d}{dz} \left( \frac{z}{(z-1)^2} \right) = (-z) \left[ \frac{z-1^2 - z \cdot 2(z-1)}{(z-1)^4} \right] = \frac{z^2 + z}{(z-1)^3}$$

### 5. State Initial & Final value theorem on Z Transform

**Initial Value Theorem**

$$\text{If } Z[f(n)] = F(z) \text{ then } f(0) = \lim_{z \rightarrow \infty} F(z)$$

**Final Value Theorem**

$$\text{If } Z[f(n)] = F(z) \text{ then } \lim_{n \rightarrow \infty} f(n) = \lim_{z \rightarrow 1} (z-1)F(z)$$

### 6. State convolution theorem of Z- Transform.

**Answer:**

$$Z[f(n)] = F(z) \text{ and } Z[g(n)] = G(z) \text{ then } Z\{f(n) * g(n)\} = F(z) \cdot G(z)$$

### 7. Find Z –Transform of na<sup>n</sup>

**Answer:**

$$\begin{aligned} Z[f(n)] &= \sum_{n=0}^{\infty} f(n) z^{-n} \\ Z(na^n) &= \sum_{n=0}^{\infty} na^n z^{-n} \\ &= \sum_{n=0}^{\infty} n \left( \frac{a}{z} \right)^n = 0 + \left( \frac{a}{z} \right)^1 + 2 \left( \frac{a}{z} \right)^2 + 3 \left( \frac{a}{z} \right)^3 + \dots \\ &= \frac{a}{z} \left( 1 - \frac{a}{z} \right)^{-2} = \frac{az}{(z-a)^2} \end{aligned}$$

### 8. Find Z – Transform of $\cos \frac{n\pi}{2}$ and $\sin \frac{n\pi}{2}$

**Answer:** We know that  $Z[f(n)] = \sum_{n=0}^{\infty} f(n) z^{-n}$

$$Z \cos n\theta = \frac{z \cdot z - \cos \theta}{z^2 - 2z \cos \theta + 1} \Rightarrow Z \left[ \cos n \frac{\pi}{2} \right] = \frac{z \left( z - \cos \frac{\pi}{2} \right)}{z^2 - 2z \cos \frac{\pi}{2} + 1} = \left( \frac{z^2}{z^2 + 1} \right)$$

$$\text{Similarly } Z \sin n\theta = \frac{z \sin \theta}{z^2 - 2z \cos \theta + 1} \Rightarrow Z \left[ \sin n \frac{\pi}{2} \right] = \frac{z \sin \frac{\pi}{2}}{z^2 - 2z \cos \frac{\pi}{2} + 1} = \frac{z}{z^2 + 1}$$

9. Find Z – Transform of  $\left( \frac{1}{n} \right)$

**Answer:**  $Z[f(n)] = \sum_{n=0}^{\infty} f(n) z^{-n}$

$$Z\left(\frac{1}{n}\right) = \sum_{n=0}^{\infty} \frac{1}{n} z^{-n}$$

$$= \sum_{n=1}^{\infty} \frac{1}{n} z^{-n} = \frac{z^{-1}}{1} + \frac{z^{-2}}{2} + \frac{z^{-3}}{3} + \dots$$

$$= -\log\left(1 - \frac{1}{z}\right) = \log\left(\frac{z-1}{z}\right)^{-1}$$

$$= \log\left(\frac{z}{z-1}\right)$$

10. Find Z – Transform of  $\left( \frac{1}{n!} \right)$

**Answer:**

$$Z[f(n)] = \sum_{n=0}^{\infty} f(n) z^{-n}$$

$$Z\left(\frac{1}{n!}\right) = \sum_{n=0}^{\infty} \frac{1}{n!} z^{-n}$$

$$\sum_{n=0}^{\infty} \frac{1}{n!} z^{-n} = 1 + \frac{z^{-1}}{1!} + \frac{z^{-2}}{2!} + \frac{z^{-3}}{3!} + \dots$$

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

11. Find Z – Transform of  $\frac{1}{n+1}$

**Answer:**

$$\begin{aligned} Z[f(n)] &= \sum_{n=0}^{\infty} f(n) z^{-n} \\ Z\left(\frac{1}{n+1}\right) &= \sum_{n=0}^{\infty} \frac{1}{n+1} z^{-n} \\ &= z \sum_{n=0}^{\infty} \frac{1}{n+1} z^{-(n+1)} \\ &= z \left[ z^{-1} + \frac{z^{-2}}{2} + \frac{z^{-3}}{3} + \dots \right] \\ &= z \left( -\log \left( 1 - \frac{1}{z} \right) \right) \\ &= z \log \left( \frac{z}{z-1} \right) \end{aligned}$$

12. State and prove First shifting theorem

**Statement:** If  $Z[f(t)] = F(z)$ , then  $Z[e^{-at}f(t)] = F(ze^{aT})$

**Proof:**

$$Z[e^{-at}f(t)] = \sum_{n=0}^{\infty} e^{-anT} f(nT) z^{-n}$$

As  $f(t)$  is a function defined for discrete values of  $t$ , where  $t = nT$ ,

then the Z-transform is

$$\begin{aligned} Z[f(t)] &= \sum_{n=0}^{\infty} f(nT) z^{-n} = F(z). \\ Z[e^{-at}f(t)] &= \sum_{n=0}^{\infty} f(nT) ze^{aT} z^{-n} = F(ze^{aT}) \end{aligned}$$

13. Define unit impulse function and unit step function.

The unit sample sequence is defined as follows:

$$\delta(n) = \begin{cases} 1 & \text{for } n = 0 \\ 0 & \text{for } n \neq 0 \end{cases}$$

The unit step sequence is defined as follows:

$$u(n) = \begin{cases} 1 & \text{for } n \geq 0 \\ 0 & \text{for } n < 0 \end{cases}$$

14. Find Z – Transform of  $Ze^{at}$

**Answer:**

$$\begin{aligned} Ze^{at} &= \sum_{n=0}^{\infty} e^{anT} z^{-n} = \sum_{n=0}^{\infty} e^{aT} z^{-n} = z e^{aT} \sum_{n=0}^{\infty} z^{-n-1} \\ &= \frac{z}{z - e^{aT}} \left[ z a^n = \frac{z}{z - a} \right] \quad [\text{Using First shifting theorem}] \end{aligned}$$

15. Find Z – Transform of  $Z te^{-2t}$

Answer:

$$\begin{aligned} Z te^{-2t} &= Z t \Big|_{z=ze^{2T}} = \left( \frac{Tz}{z-1} \right)_{z=ze^{2T}} \\ &= \left( \frac{Tze^{2T}}{ze^{2T}-1} \right) \quad [\text{Using First shifting theorem}] \end{aligned}$$

16. Find Z – Transform of  $Z e^t \cos 2t$

Answer:

$$\begin{aligned} Z e^t \cos 2t &= Z \cos 2t \Big|_{z=ze^{-T}} = \left( \frac{z(z-\cos \theta)}{z^2-2\cos \theta z+1} \right)_{z=ze^{-T}} \\ &= \left( \frac{ze^{-T}(ze^{-T}-\cos T)}{ze^{-2T}-2\cos T ze^{-T}+1} \right) [\text{Using First shifting theorem}] \end{aligned}$$

17. Find Z – Transform of  $Z e^{2t+T}$

Answer: Let  $f(t) = e^{2t}$ , by second shifting theorem

$$\begin{aligned} Z e^{2(t+T)} &= Z f(t+T) = z F(z) - f(0) \\ &= z \left( \frac{ze^{-2T}}{ze^{-2T}-1} - 1 \right) = z \left( \frac{1}{ze^{-2T}-1} \right) \end{aligned}$$

18. Find Z – Transform of  $Z \sin t + T$

Answer: Let  $f(t) = \sin t$ , by second shifting theorem

$$\begin{aligned} Z \sin(t+T) &= Z f(t+T) = z F(z) - f(0) \\ &= z \left( \frac{z \sin t}{z^2-2\cos t z+1} - 0 \right) = \left( \frac{z^2 \sin t}{z^2-2\cos t z+1} \right) \end{aligned}$$

20. Find Z – transform of  $\frac{n+1}{n+2}$

Answer:  $Z[f(n)] = \sum_{n=0}^{\infty} f(n) z^{-n}$

$$\begin{aligned} Z \left[ \frac{n+1}{n+2} \right] &= Z \left[ \frac{n^2+2n+n+2}{n+2} \right] \\ &= Z \left[ \frac{n^2+3n+2}{n+2} \right] = z \left[ \frac{n^2}{n+2} \right] + 3z \left[ \frac{n}{n+2} \right] + 2z \left[ \frac{1}{n+2} \right] \\ &= \frac{z^2+z}{z-1} + 3 \frac{z}{z-1} + 2 \frac{z}{z-1} \end{aligned}$$

**PART-B**

1. Find (i)  $Z^{-1}\left[\frac{8z^2}{(2z-1)(4z+1)}\right]$  (ii)  $Z^{-1}\left[\frac{8z^2}{(2z-1)(4z-1)}\right]$  by convolution theorem.
2. Find (i)  $Z^{-1}\left[\frac{z^2}{(z-a)(z-b)}\right]$  (ii)  $Z^{-1}\left[\frac{z^2}{(z-1)(z-3)}\right]$  by convolution theorem
3. Find (i)  $Z^{-1}\left[\frac{z^2}{(z+a)^2}\right]$  (ii)  $Z^{-1}\left[\frac{z^2}{(z-a)^2}\right]$  by convolution theorem
4. (i) State and prove Initial & Final value theorem.  
(ii) State and prove Second shifting theorem
5. Find the Z transform of (i)  $\left(\frac{1}{(n+1)(n+2)}\right)$  (ii)  $\left(\frac{2n+3}{(n+1)(n+2)}\right)$
6. (i) Find  $Z^{-1}\left[\frac{z^2}{(z^2+4)}\right]$  by residues.  
(ii) Find the inverse Z transform of  $\frac{z^2+z}{z-1(z^2+1)}$  by partial fractions.
7. Find (i)  $Z^{-1}\left[\frac{z}{z^2-2z+2}\right]$  (ii)  $Z^{-1}\left[\frac{z^2}{z^2-7z+10}\right]$
8. (i) Find the Z transform of  $f(n) = \frac{1}{n!}$  Hence find  $Z\left[\frac{1}{(n+1)!}\right]$  and  $Z\left[\frac{1}{(n+2)!}\right]$ .  
(ii) Find  $Z\left[\frac{1}{n!}\right]$  and also find the value of  $\sin(n+1)\theta$  and  $\cos(n+1)\theta$ .
9. Solve  $y_{n+2} + 6y_{n+1} + 9y_n = 2^n$  with  $y_0 = 0$  &  $y_1 = 0$
10. Solve  $y_{n+2} - 4y_{n+1} + 4y_n = 0$   $y(0) = 1$ ,  $y(1) = 0$
11. Solve  $y_n - 3y_{n-1} - 4y_{n-2} = 0, n \geq 2$  given  $y(0) = 3$  &  $y(1) = -2$
12. Solve  $y_{n+3} - 3y_{n+1} + 2y_n = 0$ ,  $y_0 = 4$ ,  $y_1 = 0$  &  $y_2 = 8$ ,
13. Find  $Z \cos n\theta$  &  $Z \sin n\theta$  and also find  $Z[a^n \cos n\theta]$  &  $Z[a^n \sin n\theta]$