TOPIC : 5 – ODD AND EVEN FUNCTIONS

Even function:

If $f(x)$ is an even function, then

$f(x) = f(-x) \Rightarrow b_n = 0.$

Ex: $\cos x$, $|x|$, x^2.

$f(x) = x^2 \Rightarrow f(-x) = (-x)^2 = x^2 = f(x)$

$\therefore f(x) = f(-x)$.

$\therefore f(x)$ is an even function $\Rightarrow b_n = 0$.

Odd function:

If $f(x)$ is an odd function, then

$-f(x) = +f(-x)$.

Ex: $f(x) = x^3$, $\sin x$, x^3, $x\cos x$.

$\Rightarrow f(-x) = (-x)^3 = -x^3 = -f(x)$

$\therefore f(-x) = -f(x)$

$\therefore f(x)$ is an odd function $\Rightarrow a_0 = 0$ & $a_n = 0$

Problems based on $(-\pi, \pi)$ & $(-l, l)$

First check whether the function is odd or even.

If the function is even using the fourier formula in the interval $(-\pi, \pi)$.

$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos nx$ Here $b_n = 0$.

If the function is odd using the fourier formula in the interval $(-\pi, \pi)$.

$$f(x) = \sum_{n=1}^{\infty} b_n \sin nx$$

where $$b_n = \frac{2}{b-a} \int_a^b f(x) \sin nx \, dx$$

Here $a_0 = 0$ & $a_n = 0$.

If the function is even using the fourier formula in the interval $(-l, l)$

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

where $$a_0 = \frac{2}{b-a} \int_{-l}^{l} f(x) \, dx$$

$$a_n = \frac{2}{b-a} \int_a^b f(x) \cos \frac{n\pi x}{l} \, dx.$$

If the function is odd using the function in the interval $(-l, l)$ fourier formula

$$f(x) = \sum_{n=1}^{\infty} b_n \sin \frac{n\pi x}{l}$$

where $$b_n = \frac{2}{b-a} \int_{-l}^{l} f(x) \sin \frac{n\pi x}{l} \, dx.$$

and deduce that

$$\frac{1}{1^2}+\frac{1}{3^2}+\frac{1}{5^2}+\cdots=\frac{\pi}{8}$$

Sol:

$$f(-x)=\begin{cases}1-\frac{2x}{\pi}, & -\pi\le -x\le 0\\ 1+\frac{2x}{\pi}, & 0\le -x\le \pi\end{cases}$$

$$=\begin{cases}1-\frac{2x}{\pi}, & 0\le x\le \pi\\ 1+\frac{2x}{\pi}, & -\pi\le x\le 0\end{cases}$$

$$f(-x)=f(x).$$

$\therefore$ $f(x)$ is even $\Rightarrow b_n=0$

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

$$a_0=\frac{2}{b-a}\int_a^b f(x)\,dx$$

$$=\frac{2}{2\pi}\int_{-\pi}^{\pi}f(x)\,dx$$

$$=\frac{2}{\pi}\int_0^{\pi}f(x)\,dx=\frac{2}{\pi}\int_0^{\pi}\left(1-\frac{2x}{\pi}\right)dx$$

$$=\frac{2}{\pi}\left[x-\frac{2x^2}{2\pi}\right]_0^{\pi}$$

$$=\frac{2}{\pi}\left[\pi-\frac{\pi^2}{\pi}\right]=\cancel{\frac{2}{\pi}\cdot 2\pi}$$

$$a_0=0.$$

$$a_n=\frac{2}{\ldots}\int^{b}f(x)\cos nx\,dx$$

$$a_n = \frac{2}{\pi}\int_0^{\pi}\left(1-\frac{2x}{\pi}\right)\cos nx\, dx$$

Here $u = 1-\frac{2x}{\pi}$ $\qquad \int dv = \int \cos nx\, dx$

$u_1 = -\frac{2}{\pi}$ $\qquad v = \frac{\sin nx}{n}$

$u_2 = 0$ $\qquad v_1 = -\frac{\cos nx}{n^2}$

$$a_n = \frac{2}{\pi}\left[\left(1-\frac{2x}{\pi}\right)\frac{\sin nx}{n} - \frac{2\cos nx}{\pi n^2}\right]_0^{\pi}$$

$$= \frac{2}{\pi}\left[\left(1-\frac{2\pi}{\pi}\right)\frac{\sin n\pi}{n} - \frac{2\cos n\pi}{\pi n^2} + \frac{2}{\pi n^2}\right]$$

$$= \frac{2}{\pi}\left[\frac{-2(-1)^n}{\pi n^2} + \frac{2}{\pi n^2}\right]$$

$$a_n = \frac{4}{\pi n^2}\left[1-(-1)^n\right]$$

$$a_n = \begin{cases} \frac{8}{\pi n^2} & \text{if } n \text{ is odd} \\ 0 & \text{if } n \text{ is even} \end{cases}$$

$$f(x) = \sum_{n=odd}^{\infty} \frac{8}{\pi n^2} \cos nx.$$

$$1 = \frac{8}{\pi}\sum_{n=odd}^{\infty} \frac{1}{n^2}\cos nx.$$

$$\frac{\pi}{8} = \frac{1}{1^2} + \frac{1}{3^2} + \frac{1}{5^2} + \cdots$$

$f(x) = |\cos x|$.

and deduce that

$$\frac{1}{1^2}+\frac{1}{3^2}+\frac{1}{5^2}+\cdots=\frac{\pi}{8}$$

<u>Sol:</u>

$$f(-x)=\begin{cases}1-\frac{2x}{\pi}, & -\pi\le -x\le 0\\ 1+\frac{2x}{\pi}, & 0\le -x\le \pi\end{cases}$$

$$=\begin{cases}1-\frac{2x}{\pi}, & 0\le x\le \pi\\ 1+\frac{2x}{\pi}, & -\pi\le x\le 0\end{cases}$$

$$f(-x)=f(x).$$

$\therefore f(x)$ is even $\Rightarrow b_n=0$

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

$$a_0=\frac{2}{b-a}\int_a^b f(x)\,dx$$

$$=\frac{2}{2\pi}\int_{-\pi}^{\pi} f(x)\,dx$$

$$=\frac{2}{\pi}\int_0^{\pi} f(x)\,dx=\frac{2}{\pi}\int_0^{\pi}\left(1\cancel{+}-\frac{2x}{\pi}\right)dx$$

$$=\frac{2}{\pi}\left[x\cancel{+}-\frac{2x^2}{2\pi}\right]_0^{\pi}$$

$$=\frac{2}{\pi}\left[\pi\cancel{+}-\frac{\pi^2}{\pi}\right]=\cancel{\frac{2}{\pi}\cdot 2\pi}$$

$$a_0=0.$$

$$a_n=\frac{2}{\quad}\int^{b} f(x)\cos nx\,dx$$

$f(x)$ is even. $\Rightarrow b_n = 0$

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

$$a_0 = \frac{2}{b-a} \int_{-\pi}^{\pi} f(x)\,dx$$

$$= \frac{2}{2\pi} \int_{-\pi}^{\pi} |\cos x|\,dx = \frac{2}{\pi} \int_0^{\pi} |\cos x|\,dx$$

$$= \frac{2}{\pi} \left\{ \int_0^{\pi/2} \cos x\,dx + \int_{\frac{\pi}{2}}^{\pi} (-\cos x)\,dx \right\}$$

$$= \frac{2}{\pi} \left\{ (\sin x)_0^{\frac{\pi}{2}} - (\sin x)_{\pi/2}^{\pi} \right\}$$

$$= \frac{2}{\pi} \left\{ \sin\frac{\pi}{2} - \sin 0 - \sin\pi + \sin\frac{\pi}{2} \right\}$$

$$= \frac{2}{\pi} \{ 2 \} = \frac{4}{\pi}$$

$$a_0 = \frac{4}{\pi}$$

$$a_n = \frac{2}{2\pi} \int_{-\pi}^{\pi} |\cos x| \cos nx\,dx$$

$$= \frac{2}{\pi} \int_0^{\pi} |\cos x| \cos nx\,dx$$

$$= \frac{2}{\pi} \left\{ \int_0^{\pi/2} \cos x \cos nx\,dx - \int_{\pi/2}^{\pi} \cos x \cos nx\,dx \right\}$$

$$a_n = \frac{1}{\pi}\left[\left(\frac{\sin(n+1)x}{n+1} + \frac{\sin(n-1)x}{n-1}\right)_0^{\pi/2} - \left(\frac{\sin(n+1)x}{n+1} + \frac{\sin(n-1)x}{n-1}\right)_{\pi/2}^{\pi}\right]$$

$$= \frac{1}{\pi}\left[\frac{\sin(n+1)\pi/2}{n+1} + \frac{\sin(n-1)\pi/2}{n-1} + \frac{\sin(n+1)\pi/2}{n+1} + \frac{\sin(n-1)\pi/2}{n-1}\right]$$

$$= \frac{1}{\pi}\left[\frac{2\sin(n+1)\pi/2}{n+1} + \frac{2\sin(n-1)\pi/2}{n-1}\right]$$

$$= \frac{2}{\pi}\left[\frac{\sin n\pi/2 \cos\pi/2 + \cos n\pi/2 \sin\pi/2}{n+1} + \frac{\sin\frac{n\pi}{2}\cos\frac{\pi}{2} - \cos\frac{n\pi}{2}\sin\frac{\pi}{2}}{n-1}\right]$$

$$= \frac{2}{\pi}\left[\frac{\cos\frac{n\pi}{2}}{n+1} - \frac{\cos\frac{n\pi}{2}}{n-1}\right]$$

$$= \frac{2}{\pi}\,\frac{\cos n\pi/2}{n^2-1}\,[n-1-n-1]$$

$$a_n = \frac{-4}{\pi}\,\frac{\cos n\pi/2}{n^2-1}.$$

$$a_1 = \frac{2}{\ }\left\{\int^{\pi/2} \cos x\cos x\,dx - \int^{\pi} \cos x\cos x\,dx\right\}$$

$$= \frac{2}{\pi}\int_0^{\pi/2}\left(\frac{1+\cos 2x}{2}\right)dx - \int_{\pi/2}^{\pi}\left(\frac{1+\cos 2x}{2}\right)dx$$

$$a_1 = \frac{2}{\pi}\left[\left(\frac{1}{2}x+\frac{\sin 2x}{4}\right)_0^{\pi/2} - \left(\frac{1}{2}x+\frac{\sin 2x}{4}\right)_{\pi/2}^{\pi}\right]$$

$$= \frac{2}{\pi}\left[\frac{1}{2}\cdot\frac{\pi}{2}+\frac{\sin 2\pi/2}{4} - \frac{1}{2}\pi - \frac{\sin 2\pi}{4} + \frac{1}{2}\cdot\frac{\pi}{2} + \frac{\sin 2\pi/2}{4}\right]$$

$$= \frac{2}{\pi}\left[\frac{\pi}{4}-\frac{\pi}{2}+\frac{\pi}{4}\right]$$

$$= \frac{2}{\pi}\left[\frac{2\pi}{4}-\frac{\pi}{2}\right]$$

$$a_1 = 0.$$

$$f(x) = \frac{4}{\pi\cdot 2} + \sum_{n=2}^{\infty}\frac{-4}{\pi}\cdot\frac{\cos n\pi/2}{n^2-1}$$

$$f(x) = \frac{2}{\pi} - \frac{4}{\pi}\sum_{n=2}^{\infty}\frac{\cos n\pi/2}{n^2-1}.$$

Problems based on odd function:

1) Determine the fourier series for the functi

$$f(x) = \begin{cases} -1+x, & -\pi < x < 0 \\ 1+x, & 0 < x < \pi \end{cases}$$ & hence dedu

Given $f(x) = \begin{cases} x-1 & -\pi < x < 0 \\ 1+x & 0 < x < \pi \end{cases}$

$$f(-x) = \begin{cases} -x-1 & -\pi < -x < 0 \\ 1-x & 0 < -x < \pi \end{cases}$$

$$= -\begin{cases} x+1 & 0 < x < \pi \\ x-1 & -\pi < x < 0 \end{cases}$$

$$f(-x) = -f(x)$$

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

$$\therefore f(x) = \sum_{n=1}^{\infty} b_n \sin nx.$$

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

$$= \frac{2}{\pi} \int_0^{\pi} x+1 \ \sin nx \, dx$$

$$= \frac{2}{\pi} \left[-(x+1)\frac{\cos nx}{n} + \frac{\sin nx}{n^2} \right]_0^{\pi}$$

$$= \frac{2}{\pi} \left[-(\pi+1) \frac{\cos n\pi}{n} + \frac{\sin n\pi}{n^2} + \frac{1}{n} \right]$$

$$= \frac{2}{\pi} \left[-(\pi+1) \frac{(-1)^n}{n} + \frac{1}{n} \right]$$

$$b_n = \frac{2}{n\pi} \left[1 - (1+\pi)(-1)^n \right]$$

2. Prove that $\frac{x(\pi^2-x^2)}{12} = \frac{\sin x}{1^3} - \frac{\sin 2x}{2^3} - \frac{\sin 3x}{3^3} + \cdots$

in the interval $(-\pi, \pi)$.

Sol:

Let $f(x) = \frac{x(\pi^2-x^2)}{12}$

$$f(-x) = (-x)\left(\frac{\pi^2-(-x)^2}{12}\right)$$

$$= -x\left(\frac{\pi^2-x^2}{12}\right)$$

$$f(-x) = -f(x)$$

$f(x)$ is an odd function $\Rightarrow a_0 = 0$ & $a_n = 0$

Let the required fourier series be

$$f(x) = \sum_{n=1}^{\infty} b_n \sin nx.$$

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

$$= \frac{2}{\pi}\int_0^{\pi} \frac{x(\pi^2-x^2)}{12}\sin nx\,dx.$$

$u = x\pi^2 - x^3$ $\int dv = \int \sin nx$

$u_1 = \pi^2 - 3x^2$ $v = \frac{-\cos nx}{n}$

$u_2 = -6x$ $v_1 = \frac{-\sin nx}{n^2}$

$u_3 = -6$ $v_2 = \frac{\cos nx}{n^3}$

$$= \frac{2}{12\pi}\int_0^{\pi}(\pi^2 x - x^3)\sin nx\,dx$$

$$= \frac{1}{6\pi}\left[-(\pi^2 x - x^3)\frac{\cos nx}{n} + (\pi^2-3x^2)\frac{\sin nx}{n^2} - 6x\frac{\cos nx}{n^3} + 6\frac{\sin nx}{n^4}\right]_0^{\pi}$$

$$b_n = -\frac{\cos n\pi}{n^3}$$

$$= -\frac{(-1)^n}{n^3}$$

$$\therefore f(x) = -\sum_{n=1}^{\infty} \frac{(-1)^n}{n^3} \sin nx.$$

$$\frac{x(\pi^2 - x^2)}{12} = \frac{\sin x}{1^3} - \frac{\sin 2x}{2^3} + \frac{\sin 3x}{3^3} + \cdots$$

(3) $f(x) = x^2 + x$ in $(-\pi, \pi)$ & $\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$.

Sol:

$$f(x) = x + x^2$$
$$f(-x) = -x + (-x)^2$$
$$= -x + x^2$$
$$f(x) \neq f(-x)$$
$$f(x) = -f(x)$$

$\therefore$ $f(x)$ is neither even nor odd.

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

$$a_0 = \frac{2}{2\pi}\int_{-\pi}^{\pi} f(x)\,dx$$

$$= \frac{1}{\pi}\int_{-\pi}^{\pi} x + x^2\,dx$$

$$= \frac{1}{\pi}\left(\frac{x^2}{2} + \frac{x^3}{3}\right)_{-\pi}^{\pi}$$

$$= \frac{1}{\pi}\left[\frac{\pi^2}{2} + \frac{\pi^3}{3} - \frac{\pi^2}{2} + \frac{\pi^3}{3}\right]$$

$$a_n = \frac{2}{2\pi}\int_{-\pi}^{\pi} f(x)\cos nx\,dx$$

$$= \frac{1}{\pi}\int_{-\pi}^{\pi} x+x^2 \cos nx\,dx$$

$$= \frac{1}{\pi}\left[(x+x^2)\frac{\sin nx}{n} + (1+2x)\frac{\cos nx}{n^2} - 2\frac{\sin nx}{n^3}\right]_{-\pi}^{\pi}$$

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

$$= \frac{1}{\pi}\left[(1+2\pi)\frac{(-1)^n}{n^2} - (1-2\pi)\frac{(-1)^n}{n^2}\right]$$

$$= \frac{(-1)^n}{n^2\pi}\left[\cancel{1}+2\pi-\cancel{1}+2\pi\right]$$

$$= \frac{(-1)^n 4\pi}{n^2\pi}$$

$$a_n = \frac{4(-1)^n}{n^2}.$$

$$b_n = \frac{2}{2\pi}\int_{-\pi}^{\pi} x+x^2 \sin nx\,dx$$

$$= \frac{1}{\pi}\left[(x+x^2)\frac{\cos nx}{n} + (1+2x)\frac{\sin nx}{n^2} + \frac{2\cos nx}{n^3}\right]_{-\pi}^{\pi}$$

$$= \frac{1}{\pi}\left[-(\pi+\pi^2)\frac{(-1)^n}{n} + \frac{2(-1)^n}{n^3} + (-\pi+\pi^2)\frac{\cos n(-\pi)}{n} - \frac{2\cos n(-\pi)}{n^3}\right]$$

$$b_n = \frac{1}{\pi}\left[\frac{-\pi(-1)^n}{n} - \cancel{\frac{\pi^2(-1)^n}{n}} - \frac{\pi(-1)^n}{n} + \cancel{\frac{\pi^2(-1)^n}{n}}\right]$$

$$= \frac{1}{\pi}\left[\frac{-2\pi(-1)^n}{n}\right]$$

$$b_n = \frac{2(-1)^{n+1}}{n}$$

$$b_n = \begin{cases} \frac{2}{n} & \text{if } n \text{ is odd} \\ -\frac{2}{n} & \text{if } n \text{ is even} \end{cases}$$

$$f(x) = \frac{\cancel{2}\pi^2}{3\cdot\cancel{2}} + \sum_{n=1}^{\infty} \frac{4(-1)^n}{n^2}\cos nx + \sum_{n=1}^{\infty}\frac{2(-1)^{n+1}}{n}\sin nx$$

If $x=0, x=\pi$

$$\pi+\pi^2 = \frac{2\pi^2}{3} + \sum_{n=1}^{\infty}\frac{4(-1)^n}{n^2}\cos n\pi$$

$$\pi+\pi^2 - \frac{2\pi^2}{3} = 4\sum_{n=1}^{\infty}\frac{(-1)^n(-1)^n}{n^2}$$

If $x=\pi$ (discontinuous & end point)

$$\frac{f(-\pi)+f(\pi)}{2} = \frac{\pi^2}{3} + 4\sum_{n=1}^{\infty}\frac{(-1)^n(-1)^n}{n^2}$$

$$\frac{\cancel{-\pi}+\pi^2+\cancel{\pi}+\pi^2}{2} = \frac{\pi^2}{3} + 4\sum_{n=1}^{\infty}\frac{(-1)^{2n}}{n^2}$$

$$\pi^2 - \frac{\pi^2}{3} = 4\sum_{n=1}^{\infty}\frac{(-1)^{2n}}{n^2}$$

$$\frac{2\pi^2}{3\cdot 4} = \frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{3^2}+\cdots$$

$$\frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{3^2}+\cdots = \frac{\pi^2}{6}.$$