Exercise 3.3.3

For the following functions, sketch the Fourier sine series of $f(x)$. Also, roughly sketch the sum of a *finite* number of nonzero terms (at least the first two) of the Fourier sine series:

(a) $f(x) = \cos \pi x/L$ [Use formula (3.3.13).]

(b) $f(x) = \begin{cases} 1 & x < L/2 \\ 0 & x > L/2 \end{cases}$

(c) $f(x) = x$ [Use formula (3.3.12).]

Solution

Assume that $f(x)$ is a piecewise smooth function on the interval $0 \leq x \leq L$. The odd extension of $f(x)$ to the whole line with period $2L$ is given by the Fourier sine series expansion,

$$f(x) = \sum_{n=1}^{\infty} B_n \sin \frac{n\pi x}{L},$$

at points where $f(x)$ is continuous and by the average of the left-hand and right-hand limits at points of discontinuity. The coefficients B_n are obtained by multiplying both sides by $\sin \frac{p\pi x}{L}$ (p being an integer), integrating both sides with respect to x from 0 to L, and taking advantage of the fact that sine functions are orthogonal with one another.

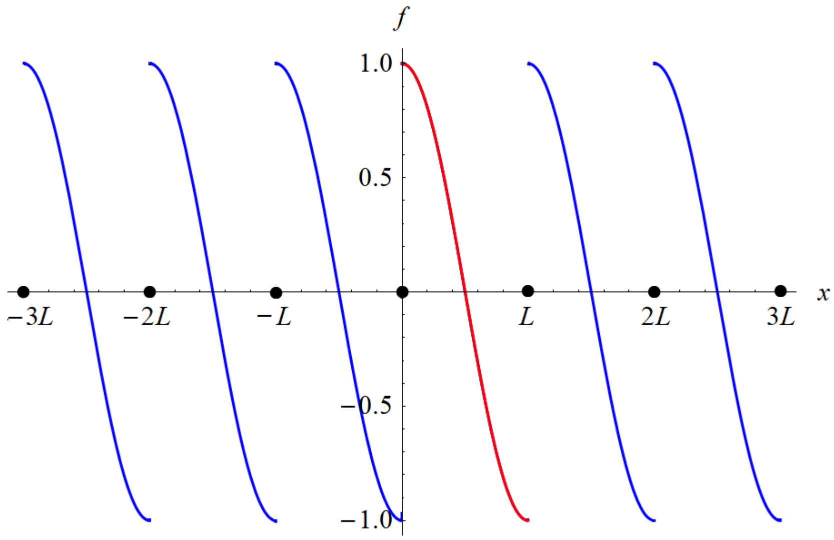
$$B_n = \frac{2}{L} \int_0^L f(x) \sin \frac{n\pi x}{L}\, dx$$

Part (a)

For $f(x) = \cos \pi x/L$, the coefficients are

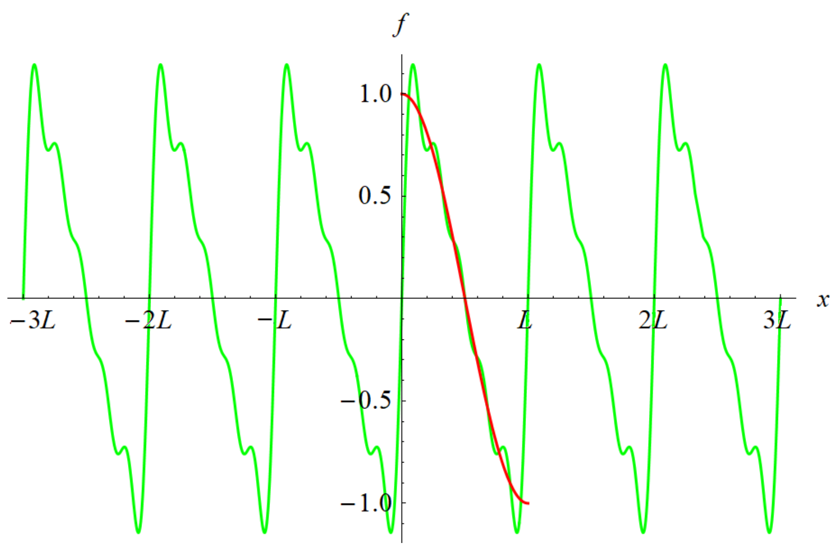
$$\begin{aligned}
B_n &= \frac{2}{L} \int_0^L \cos \frac{\pi x}{L} \sin \frac{n\pi x}{L}\, dx \\
&= \frac{2}{L} \int_0^L \frac{1}{2} \left[\sin\left(\frac{\pi x}{L} + \frac{n\pi x}{L}\right) - \sin\left(\frac{\pi x}{L} - \frac{n\pi x}{L}\right)\right] dx \\
&= \frac{1}{L} \left[\int_0^L \sin \frac{(1+n)\pi x}{L}\, dx - \int_0^L \sin \frac{(1-n)\pi x}{L}\, dx\right] = 0 \quad \text{if } n = 1 \\
&= \frac{1}{L} \left[\frac{[1+(-1)^n]L}{(1+n)\pi} - \frac{[1+(-1)^n]L}{(1-n)\pi}\right] \quad \text{if } n \neq 1 \\
&= \begin{cases} 0 & n = 1 \\ \dfrac{2[1+(-1)^n]n}{(n^2-1)\pi} & n \neq 1 \end{cases} \\
&= \begin{cases} 0 & n \text{ odd} \\ \dfrac{4n}{(n^2-1)\pi} & n \text{ even} \end{cases}.
\end{aligned}$$

Below is a graph of the function and its odd extension to the whole line.



Below is a plot of the first ten terms in the infinite series:

$$f(x) \approx \sum_{n=1}^{10} B_n \sin \frac{n\pi x}{L}.$$

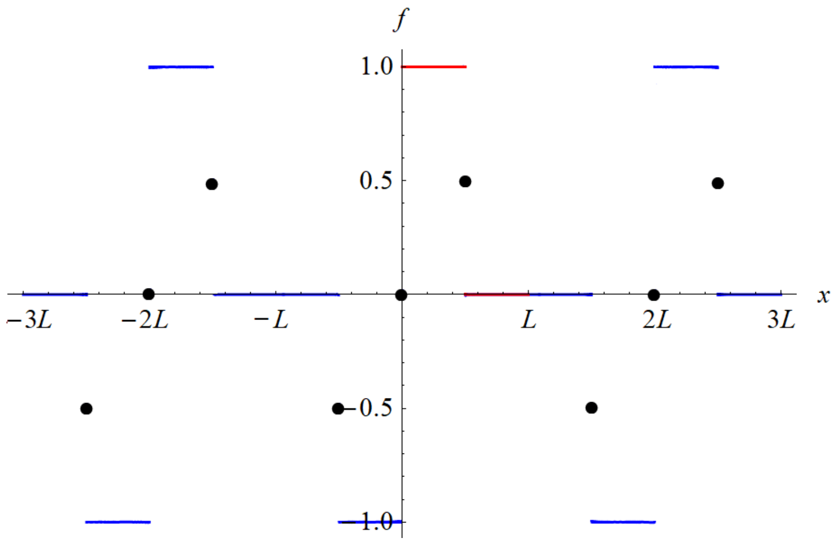


Part (b)

For $f(x) = 1$ if $x < L/2$ and $f(x) = 0$ if $x > L/2$, the coefficients are

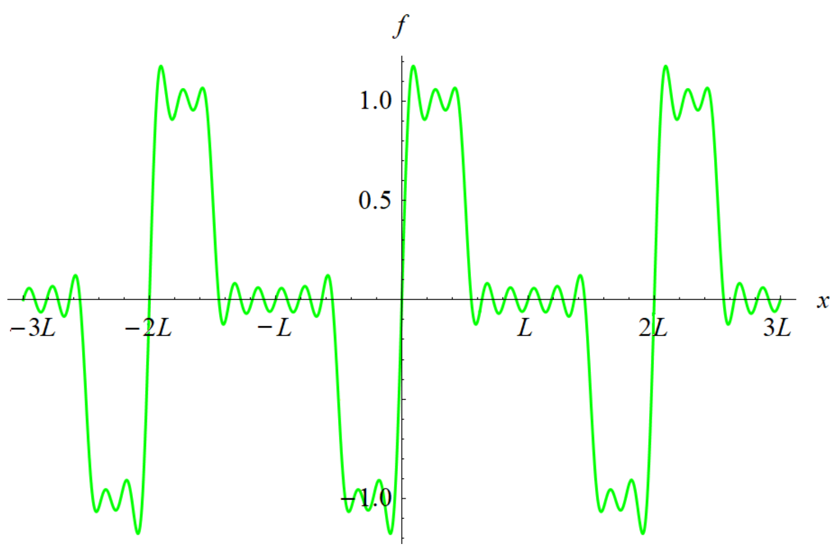
$$B_n = \frac{2}{L}\left(\int_0^{L/2} \sin\frac{n\pi x}{L}\,dx + \int_{L/2}^{L} 0\sin\frac{n\pi x}{L}\,dx\right) = \frac{4}{n\pi}\sin^2\frac{n\pi}{4}.$$

Below is a graph of the function and its odd extension to the whole line.



Below is a plot of the first ten terms in the infinite series:

$$f(x) \approx \sum_{n=1}^{10} B_n \sin\frac{n\pi x}{L}.$$

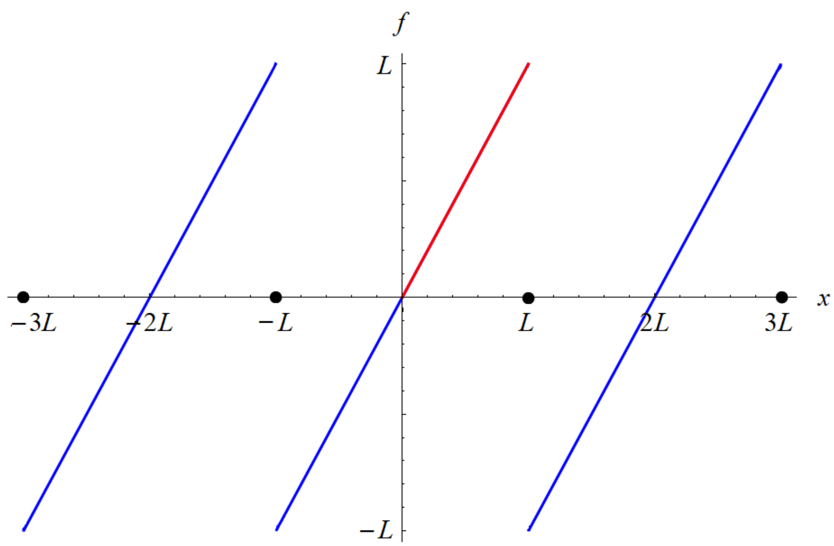


Part (c)

For $f(x) = x$, the coefficients are

$$B_n = \frac{2}{L}\int_0^L x \sin\frac{n\pi x}{L}\,dx = -\frac{2(-1)^n L}{n\pi}.$$

Below is a graph of the function and its odd extension to the whole line.



Below is a plot of the first ten terms in the infinite series:

$$f(x) \approx \sum_{n=1}^{10} B_n \sin\frac{n\pi x}{L}.$$