

# Module 7 Notes (MATH-211)

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## General Notes (and Definitions)

- Working with Integrals

A function  $f(x)$  is **even** if  $f(-x) = f(x)$ .

A function  $f(x)$  is **odd** if  $f(-x) = -f(x)$ .

Let  $a \in \mathbb{R}$  such that  $a > 0$  and let  $f$  be an integrable function on the interval  $[-a, a]$ .

$$\text{If } f \text{ is even, } \int_{-a}^a f(x) dx = 2 \int_0^a f(x) dx$$

$$\text{If } f \text{ is odd, } \int_{-a}^a f(x) dx = 0$$

The average value of an integrable function  $f$  on the interval  $[a, b]$  is

$$\bar{f} = \frac{1}{b-a} \int_a^b f(x) dx$$

Let  $f$  be continuous on the interval  $[a, b]$ . There exists a point  $c$  in  $(a, b)$  such that (Mean Value Theorem)

$$f(c) = \bar{f} = \frac{1}{b-a} \int_a^b f(t) dx$$

- Substitution Rule

Let  $u = g(x)$ , where  $g$  is differentiable on an interval, and let  $f$  be continuous on the corresponding range of  $g$ . On that interval,

$$\int f(g(x))g'(x) dx = \int f(u) du$$

1. Given an indefinite integral involving a composite function  $f(g(x))$ , identify an inner function  $u = g(x)$  such that a constant multiple of  $g'(x)$  appears in the integrand.
2. Substitute  $u = g(x)$  and  $du = g'(x) dx$  in the integral.
3. Evaluate the new indefinite integral with respect to  $u$ .
4. Write the result in terms of  $x$  using  $u = g(x)$ .

Let  $u = g(x)$ , where  $g'$  is continuous on  $[a, b]$ , and let  $f$  be continuous on the range of  $g$ . Then

$$\int_a^b f(g(x))g'(x) dx = \int_{g(a)}^{g(b)} f(u) du$$

- Velocity and Net Change

**Position, Velocity, Displacement, and Distance:**

1. The **position** of an object moving along a line at time  $t$ , denoted  $s(t)$ , is the location of the object relative to the origin.
2. The **velocity** of an object at time  $t$  is  $v(t) = s'(t)$ .
3. The **displacement** of the object between  $t = a$  and  $t = b > a$  is

$$s(b) - s(a) = \int_a^b v(t) dt$$

4. The **distance traveled** by the object between  $t = a$  and  $t = b > a$  is

$$\int_a^b |v(t)| \, dt$$

where  $|v(t)|$  is the **speed** of the object at time  $t$ .

**Theorem: Position from Velocity**

Given the velocity  $v(t)$  of an object moving along a line and its initial position  $s(0)$ , the position function of the object for future times  $t \geq 0$  is

$$s(t) = s(0) + \int_0^t v(x) \, dx$$

**Theorem: Velocity from Acceleration**

Given the acceleration  $a(t)$  of an object moving along a line and its initial velocity  $v(0)$ , the velocity of the object for future times  $t \geq 0$  is

$$v(t) = v(0) + \int_0^t a(x) \, dx$$

**Theorem: Net Change and Future Value**

Suppose a quantity  $Q$  changes over time at a known rate  $Q'$ . Then the **net change** in  $Q$  between  $t = a$  and  $t = b > a$  is

$$Q(b) - Q(a) = \int_a^b Q'(t) \, dt$$

Given the initial value  $Q(0)$ , the **future value** of  $Q$  at time  $t \geq 0$  is

$$Q(t) = Q(0) + \int_0^t Q'(x) \, dx$$

- Area Between Curves

**Area of a Region Between Two Curves:**

Suppose that  $f$  and  $g$  are continuous functions with  $f(x) \geq g(x)$  on the interval  $[a, b]$ . The area of the region bounded by the graphs of  $f$  and  $g$  on  $[a, b]$  is

$$A = \int_a^b (f(x) - g(x)) \, dx$$

**Area of a Region Between Two Curves with Respect to  $y$ :**

Suppose that  $f$  and  $g$  are continuous functions with  $f(y) \geq g(y)$  on the interval  $[c, d]$ . The area of the region bounded by the graphs  $x = f(y)$  and  $x = g(y)$  on  $[c, d]$  is

$$A = \int_c^d (f(y) - g(y)) \, dy$$

- Volume by Slicing

**General Slicing Method:**

Suppose a solid object extends from  $x = a$  to  $x = b$  and the cross section of the solid perpendicular to the  $x$ -axis has an area given by a function  $A$  that is integrable on  $[a, b]$ . The volume of the solid is

$$V = \int_a^b A(x) \, dx$$

**Disk Method about the  $x$ -Axis:**

Let  $f$  be continuous with  $f(x) \geq 0$  on the interval  $[a, b]$ . If the region  $R$  bounded by the graph of  $f$ , the  $x$ -axis, and the lines  $x = a$  and  $x = b$  is revolved about the  $x$ -axis, the volume of the resulting solid of revolution is

$$V = \int_a^b \pi f(x)^2 \, dx$$

**Washer Method about the  $x$ -Axis:**

Let  $f$  and  $g$  be continuous functions with  $f(x) \geq g(x) \geq 0$  on  $[a, b]$ . Let  $R$  be the region bounded by

$y = f(x)$ ,  $y = g(x)$ , and the lines  $x = a$  and  $x = b$ . When  $R$  is revolved about the  $x$ -axis, the volume of the resulting solid of revolution is

$$V = \int_a^b \pi (f(x)^2 - g(x)^2) dx$$

#### Disk and Washer Methods about the $y$ -Axis:

Let  $p$  and  $q$  be continuous functions with  $p(y) \geq q(y) \geq 0$  on  $[c, d]$ . Let  $R$  be the region bounded by  $x = p(y)$ ,  $x = q(y)$ , and the lines  $y = c$  and  $y = d$ . When  $R$  is revolved about the  $y$ -axis, the volume of the resulting solid of revolution is given by

$$V = \int_c^d \pi (p(y)^2 - q(y)^2) dy$$

If  $q(y) = 0$ , the disk method results:

$$V = \int_c^d \pi p(y)^2 dy$$

- Volume by Shells

#### Volume by the Shell Method:

Let  $f$  and  $g$  be continuous functions with  $f(x) \geq g(x)$  on  $[a, b]$ . If  $R$  is the region bounded by the curves  $y = f(x)$  and  $y = g(x)$  between the lines  $x = a$  and  $x = b$ , the volume of the solid generated when  $R$  is revolved about the  $y$ -axis is

$$V = \int_a^b 2\pi x (f(x) - g(x)) dx$$

## General formulas for indefinite integrals

$$\int \cos ax dx = \frac{1}{a} \sin ax + C \quad (1)$$

$$\int \sin ax dx = -\frac{1}{a} \cos ax + C \quad (2)$$

$$\int \sec^2 ax dx = \frac{1}{a} \tan ax + C \quad (3)$$

$$\int \csc^2 ax dx = -\frac{1}{a} \cot ax + C \quad (4)$$

$$\int \sec ax \tan ax dx = \frac{1}{a} \sec ax + C \quad (5)$$

$$\int \csc ax \cot ax dx = -\frac{1}{a} \csc ax + C \quad (6)$$

$$\int e^{ax} dx = \frac{1}{a} e^{ax} + C \quad (7)$$

$$\int b^x dx = \frac{1}{\ln b} b^x + C, b > 0, b \neq 1 \quad (8)$$

$$\int \frac{dx}{a^2 + x^2} = \frac{1}{a} \tan^{-1} \frac{x}{a} + C \quad (9)$$

$$\int \frac{dx}{\sqrt{a^2 - x^2}} = \sin^{-1} \frac{x}{a} + C, a > 0 \quad (10)$$

$$\int \frac{dx}{x\sqrt{x^2 - a^2}} = \frac{1}{a} \sec^{-1} \left| \frac{x}{a} \right| + C, a > 0 \quad (11)$$

## Examples

1. Use symmetry to evaluate integrals

$$\int_{-200}^{200} 2x^5 dx = 0$$

$$\int_{-2}^2 (x^2 + x^3) dx = \int_{-2}^2 x^2 dx + \int_{-2}^2 x^3 dx \quad (1)$$

$$= 2 \int_0^2 x^2 dx + 0 \quad (2)$$

$$= 2 \frac{x^3}{3} \quad (3)$$

$$= \frac{16}{3} \quad (4)$$

## 2. A derivative calculation

$$s(t) = -16t^2 + 64t$$

$$t = 4$$

$$[0, 4]$$

$$v(t) = s'(t) \quad (1)$$

$$\bar{v} = \frac{1}{4} \int_0^4 v(t) dx \quad (2)$$

$$= \frac{1}{4} \int_0^4 s'(t) dx \quad (3)$$

$$= \frac{1}{4} s(t) \quad (4)$$

$$= \frac{1}{4} (s(4) - s(0)) \quad (5)$$

$$= 0 \quad (6)$$

## 3. Applying MVT for integrals

$$f(x) = e^x$$

$$[0, 2]$$

$$\bar{f} = \frac{1}{2} \left( \int_0^2 e^x dx \right) \quad (1)$$

$$= \frac{e^x}{2} \quad (2)$$

$$= \frac{e^2}{2} - \frac{e^0}{2} \quad (3)$$

$$= \frac{e^2 - 1}{2} \quad (4)$$

$$e^x = \frac{e^2 - 1}{2} \quad (5)$$

$$\ln e^x = \ln \frac{e^2 - 1}{2} \quad (6)$$

## 4. Perfect substitutions in indefinite integrals

$$u = 4x^3 - 8 \quad (1)$$

$$du = 12x^2 dx \quad (2)$$

$$\int 12x^2 (4x^3 - 8)^5 dx = \int 12x^2 u^5 dx \quad (3)$$

$$= \frac{u^6}{6} + C \quad (4)$$

$$= \frac{(4x^3 - 8)^6}{6} + C \quad (5)$$

$$u = \sin t \quad (1)$$

$$du = \cos t \, dt \quad (2)$$

$$\int (\cos t) e^{\sin t} \, dt = \int e^u \, du \quad (3)$$

$$= e^u + C \quad (4)$$

$$= e^{\sin t} + C \quad (5)$$

## 5. Introducing constants when integrating by substitution

$$u = 6x + 4 \quad (1)$$

$$du = 6 \, dx \quad (2)$$

$$dx = \frac{du}{6} \quad (3)$$

$$\int (6x + 4)^9 \, dx = \int \frac{1}{6} \cdot u^9 \, du \quad (4)$$

$$= \frac{1}{6} \int u^9 \, du \quad (5)$$

$$= \frac{1}{6} \cdot \frac{u^{10}}{10} + C \quad (6)$$

$$= \frac{(6x + 4)^{10}}{60} + C \quad (7)$$

$$u = \cot x \quad (1)$$

$$du = -\csc^2 x \, dx \quad (2)$$

$$\int \cot^2 x \csc^2 x \, dx = \int -u^2 \, du \quad (3)$$

$$= -\frac{u^3}{3} + C \quad (4)$$

$$= -\frac{\csc^3 x}{3} + C \quad (5)$$

## 6. Variations on the substitution method

$$u = x - 1 \quad (1)$$

$$du = dx \quad (2)$$

$$x = u + 1 \quad (3)$$

$$\int x\sqrt{x-1} \, dx = \int (u+1)\sqrt{u} \, du \quad (4)$$

$$= \int u\sqrt{u} + \sqrt{u} \, du \quad (5)$$

$$= \int u^{\frac{3}{2}} + u^{\frac{1}{2}} \, du \quad (6)$$

$$= \frac{2}{5}u^{\frac{5}{2}} + \frac{2}{3}u^{\frac{3}{2}} + C \quad (7)$$

$$= \frac{2}{5}(x-1)^{\frac{5}{2}} + \frac{2}{3}(x-1)^{\frac{3}{2}} + C \quad (8)$$

## 7. Use known formulas to evaluate indefinite integrals

$$\int 2e^{-4x} \, dx = 2 \int e^{-4x} \, dx \quad (1)$$

$$= \frac{2}{-4}e^{-4x} + C \quad (2)$$

$$= -\frac{1}{2}e^{-4x} + C \quad (3)$$

$$(4)$$

$$\int \frac{dx}{\sqrt{36-x^2}} = \int \frac{dx}{\sqrt{6^2-x^2}} \quad (1)$$

$$= \sin^{-1} \frac{x}{6} + C \quad (2)$$

## 8. Evaluating definite integrals using substitution

$$u = 2^x + 4 \quad (1)$$

$$du = 2^x \ln 2 \, dx \quad (2)$$

$$\frac{1}{\ln 2} du = 2^x \, dx \quad (3)$$

$$\int_1^3 \frac{2^x}{2^x + 4} \, dx = \int_1^3 \frac{1}{u \ln 2} \, du \quad (4)$$

$$\int_{g(1)}^{g(3)} \frac{1}{u \ln 2} \, du = \int_6^{12} \frac{1}{u \ln 2} \, du \quad (5)$$

$$= \frac{1}{\ln 2} \int_6^{12} \frac{du}{u} \quad (6)$$

$$= \frac{1}{\ln 2} \cdot (\ln 12 - \ln 6) \quad (7)$$

$$= \frac{\ln 2}{\ln 2} \quad (8)$$

$$= 1 \quad (9)$$

$$u = \ln p \quad (1)$$

$$du = \frac{1}{p} \, dx \quad (2)$$

$$\int_1^{e^2} \frac{\ln p}{p} \, dx = \int_0^2 u \, du \quad (3)$$

$$= \frac{2^2}{2} - \frac{0^2}{2} \quad (4)$$

$$= \frac{4}{2} \quad (5)$$

$$= 2 \quad (6)$$

## 9. Integrals involving $\cos^2 x$ and $\sin^2 x$

$$u = 2x \quad (1)$$

$$du = 2 \, dx \quad (2)$$

$$dx = \frac{1}{2} du \quad (3)$$

$$\sin^2 x = \frac{1 - \cos 2x}{2} \quad (4)$$

$$\int_0^\pi \sin^2 x \, dx = \int_0^\pi \frac{1 - \cos 2x}{2} \, dx \quad (5)$$

$$= \frac{1}{2} \int_0^\pi 1 - \cos 2x \, dx \quad (6)$$

$$= \frac{1}{2} \left( \int_0^\pi 1 \, dx - \int_0^\pi \cos 2x \, dx \right) \quad (7)$$

$$= \frac{1}{2} \left( (\pi - 0) - \frac{1}{2} \int_0^{2\pi} \cos u \, du \right) \quad (8)$$

$$= \frac{1}{2} \left( \pi - \frac{1}{2} (\sin 2\pi - \sin 0) \right) \quad (9)$$

$$= \frac{1}{2} (\pi - 0) \quad (10)$$

$$= \frac{\pi}{2} \quad (11)$$

10. Displacement and distance from velocity

$$v(t) = 4t^3 - 24t^2 + 20t$$

(a)

$$v(t) = 0 \quad (1)$$

$$4t^3 - 24t^2 + 20t = 0 \quad (2)$$

$$4t(t^2 - 6t + 5) = 0 \quad (3)$$

$$4t(t-1)(t-5) = 5 \quad (4)$$

$$t = 0 \quad (5)$$

$$t = 1 \quad (6)$$

$$t = 5 \quad (7)$$

$$0 < t < 1 = \text{Positive} \quad (8)$$

$$1 < t < 5 = \text{Negative} \quad (9)$$

$$t > 5 = \text{Positive} \quad (10)$$

(b)

$$\int_0^5 4t^3 - 24t^2 + 20t \, dt = 4 \int_0^5 t^3 \, dt - 24 \int_0^5 t^2 \, dt + 20 \int_0^5 t \, dt \quad (1)$$

$$= 4 \left( \frac{5^4}{4} - \frac{0^4}{4} \right) - 24 \left( \frac{5^3}{3} - \frac{0^3}{3} \right) + 20 \left( \frac{5^2}{2} - \frac{0^2}{2} \right) \quad (2)$$

$$= 4 \left( \frac{625}{4} \right) - 24 \left( \frac{125}{3} \right) + 20 \left( \frac{25}{2} \right) \quad (3)$$

$$= -125 \quad (4)$$

(c)

$$\int_0^5 |4t^3 - 24t^2 + 20t| \, dt = \int_0^1 4t^3 - 24t^2 + 20t \, dt + \int_1^5 -4t^3 + 24t^2 - 20t \, dt \quad (1)$$

$$= 3 + 128 \quad (2)$$

$$= 131 \quad (3)$$

11. Position and velocity from acceleration

$$a(t) = \frac{20}{(t+2)^2}$$

$$v(0) = 20$$

$$s(0) = 10$$

$$v(t) = v(0) + \int_0^t a(t) \, dt \quad (1)$$

$$= 20 + \int_0^t \frac{20}{(t+2)^2} \, dt \quad (2)$$

$$= 20 - \frac{20}{t+2} + 10 \quad (3)$$

$$= 30 - \frac{20}{t+2} \quad (4)$$

$$s(t) = s(0) + \int_0^t v(t) \, dt \quad (5)$$

$$= 10 + \int_0^t \left( 30 - \frac{20}{t+2} \right) \, dt \quad (6)$$

$$= 10 + 30t - 20 \ln |t+2| + 20 \ln 2 \quad (7)$$

## 12. Acceleration application

$$a(t) = -15$$

$$v(0) = 60$$

$$s(0) = 0$$

$$v(t) = 60 + \int_0^t -15 \, dt \quad (1)$$

$$= 60 + -15 \int_0^t t^0 \, dt \quad (2)$$

$$= -15t + 60 \quad (3)$$

$$s(t) = 0 + \int_0^t -15t + 60 \, dt \quad (4)$$

$$= -15 \int_0^t t \, dt + 60t \quad (5)$$

$$= -\frac{15}{2}t^2 + 60t \quad (6)$$

$$v(t) = 0 \quad (7)$$

$$60 - 15t = 0 \quad (8)$$

$$15t = 60 \quad (9)$$

$$t = \frac{60}{15} \quad (10)$$

$$= 4 \quad (11)$$

$$s(4) - s(0) = 60(4) - \frac{15}{2}(4)^2 - 0 \quad (12)$$

$$= 120 \quad (13)$$

## 13. Application of net change

$$V'(t) = 70(1 + \sin 2\pi t)$$

$$[0, t]$$

$$V(0) = 0$$

$$V(t) = V(0) + \int_0^t V'(x) \, dx \quad (1)$$

$$= 0 + \int_0^t 70(1 + \sin(2\pi x)) \, dx \quad (2)$$

$$= 70 \left( t - \frac{\cos 2\pi t}{2\pi} + \frac{1}{2\pi} \right) \quad (3)$$

$$V(60) = 70 \left( 60 - \frac{\cos 120\pi}{2\pi} + \frac{1}{2\pi} \right) \quad (4)$$

$$= 70 \cdot 60 \quad (5)$$

$$= 4200 \quad (6)$$

## 14. Area between curves (one integral)

$$y = x$$

$$y = x^2 - 2$$



$$x = x^2 - 2 \quad (1)$$

$$0 = x^2 - x - 2 \quad (2)$$

$$= (x - 2)(x + 1) \quad (3)$$

$$x = -1 \quad (4)$$

$$x = 2 \quad (5)$$

$$\int_{-1}^2 x - (x^2 - 2) dx = \int_{-1}^2 -x^2 + x + 2 dx \quad (6)$$

$$= \left( \frac{-2^3}{3} + \frac{2^2}{2} + 2(2) \right) - \left( \frac{-(-1)^3}{3} + \frac{(-1)^2}{2} + 2(-1) \right) \quad (7)$$

$$= \left( \frac{-8}{3} + 6 \right) - \left( \frac{1}{3} + \frac{1}{2} - 2 \right) \quad (8)$$

$$= \frac{-9}{3} + 8 - \frac{1}{2} \quad (9)$$

$$= 5 - \frac{1}{2} \quad (10)$$

$$= 4.5 \quad (11)$$

15. Area between curves (multiple integrals)

$$y = x$$

$$y = x^3$$

$$x^3 = x \quad (1)$$

$$0 = x^3 - x \quad (2)$$

$$= x(x^2 - 1) \quad (3)$$

$$x = -1 \quad (4)$$

$$x = 0 \quad (5)$$

$$x = 1 \quad (6)$$

$$\int_{-1}^0 x^3 - x dx + \int_0^1 x - x^3 dx = - \left( \frac{(-1)^4}{4} - \frac{(-1)^2}{2} \right) + \left( \frac{1^2}{2} - \frac{(-1)^4}{4} \right) \quad (7)$$

$$= - \left( \frac{1}{4} - \frac{1}{2} \right) + \left( \frac{1}{2} - \frac{1}{4} \right) \quad (8)$$

$$= - \left( -\frac{1}{4} \right) + \frac{1}{4} \quad (9)$$

$$= \frac{1}{4} + \frac{1}{4} \quad (10)$$

$$= \frac{1}{2} \quad (11)$$

16. Area between curves (multiple integrals 2)

$$y = 4x - x^2$$

$$y = 4x - 4$$

$$[0, 2]$$

$$\int_0^1 4x - x^2 dx + \int_1^2 4x - x^2 - 4x + 4 dx = \left( 2 + \frac{1}{3} \right) + \left( \left( -\frac{2^3}{3} + 4(2) \right) - \left( -\frac{1^3}{3} + 4(1) \right) \right) \quad (1)$$

$$= \left( 2 + \frac{1}{3} \right) + \left( \left( -\frac{8}{3} + 8 \right) - \left( -\frac{1}{3} + 4 \right) \right) \quad (2)$$

$$= \frac{7}{3} + \left( \frac{16}{3} - \frac{11}{3} \right) \quad (3)$$

$$= \frac{7}{3} + \left( \frac{16}{3} - \frac{11}{3} \right) \quad (4)$$

$$= 4 \quad (5)$$

17. Area between curves (integrating  $dy$ )

$$x = \sqrt{y}$$

$$x \frac{y}{4}$$

$$\int_0^4 \left( \sqrt{y} - \frac{y}{4} \right) dy = \left( \frac{2}{3} 4^{\frac{3}{2}} - \frac{4^2}{8} \right) \quad (1)$$

$$= \left( \frac{2}{3} \cdot 8 - \frac{16}{8} \right) \quad (2)$$

$$= \left( \frac{16}{3} - 2 \right) \quad (3)$$

$$= \frac{10}{3} \quad (4)$$

18. Area between curves (choosing a method)

$$y = \sqrt{\frac{x}{2} + 1}$$

$$y = \sqrt{1 - x}$$

$$x = 2y^2 - 2 \quad (1)$$

$$x = 1 - y^2 \quad (2)$$

$$2y^2 - 2 = 1 - y^2 \quad (3)$$

$$3y^2 - 3 = 0 \quad (4)$$

$$3(y^2 - 1) = 0 \quad (5)$$

$$y = -1 \quad (6)$$

$$y = 1 \quad (7)$$

$$\int_0^1 (1 - y^2 - 2y^2 + 2) dy = \int_0^1 (3 - 3y^2) dy \quad (8)$$

$$= (3(1) - 1^3) \quad (9)$$

$$= 3 - 1 \quad (10)$$

$$= 2 \quad (11)$$

19. Using geometry to find area between curves

$$x = 2y$$

$$x = y + 1$$

$$(2, 1)$$

$$A_1 = 1 \quad (1)$$

$$A_2 = \frac{1}{2} \quad (2)$$

$$A = 1 - \frac{1}{2} \quad (3)$$

$$= \frac{1}{2} \quad (4)$$

20. Applying the general slicing method

$$y = \sqrt{1 - x^2}$$

$$S = \sqrt{1-x^2} \quad (1)$$

$$A(x) = \sqrt{1-x^2}^2 \quad (2)$$

$$= 1-x^2 \quad (3)$$

$$x = -1, 1 \quad (4)$$

$$V = \int_{-1}^1 1-x^2 dx \quad (5)$$

$$= \left(1 - \frac{1^3}{3}\right) - \left(-1 - \frac{(-1)^3}{3}\right) \quad (6)$$

$$= 1 - \frac{1}{3} + 1 - \frac{1}{3} \quad (7)$$

$$= 2 - \frac{2}{3} \quad (8)$$

$$= \frac{4}{3} \quad (9)$$

21. Graphing and applying the general slicing method

$$y = x^2 \quad (\text{Base Region})$$

$$y = 1 \quad (\text{Base Line})$$

$$S = 1-x^2 \quad (1)$$

$$A(x) = (1-x^2)^2 \quad (2)$$

$$= 1-2x^2+x^4 \quad (3)$$

$$1 = x^2 \quad (4)$$

$$x = -1, 1 \quad (5)$$

$$\int_{-1}^1 1-2x^2+x^4 dx = \left(1 - 2\frac{1^3}{3} + \frac{1^5}{5}\right) - \left(-1 - 2\frac{(-1)^3}{3} + \frac{(-1)^5}{5}\right) \quad (6)$$

$$= 1 - \frac{2}{3} + \frac{1}{5} + 1 - \frac{2}{3} + \frac{1}{5} \quad (7)$$

$$= \frac{16}{15} \quad (8)$$

22. Applying the disk method ( $x$ -axis)

$$y = e^{-x}$$

$$y = 0$$

$$x = 0$$

$$x = \ln 4$$

$$V = \int_0^{\ln 4} \pi (e^{-x})^2 dx \quad (1)$$

$$= \int_0^{\ln 4} (\pi e^{-2x}) dx \quad (2)$$

$$= \frac{15}{32}\pi \quad (3)$$

23. Applying the washer method ( $x$ -axis)

$$y = x$$

$$y = \sqrt[4]{x}$$

$$r_o = \sqrt[4]{x} \quad (1)$$

$$r_i = x \quad (2)$$

$$x = \sqrt[4]{x} \quad (3)$$

$$x^4 = x \quad (4)$$

$$0 = x^4 - x \quad (5)$$

$$= x(x^3 - 1) \quad (6)$$

$$x = 0, 1 \quad (7)$$

$$V = \int_0^1 \pi \left( (\sqrt[4]{x})^2 - x^2 \right) dx \quad (8)$$

$$= \int_0^1 \pi \left( x^{\frac{1}{2}} - x^2 \right) dx \quad (9)$$

$$= \frac{1}{3} \pi \quad (10)$$

24. Applying the washer method ( $y$ -axis)

$$y = x^3$$

$$y = 0$$

$$x = 1$$

$$r_o = 1 \quad (1)$$

$$x = y^{\frac{1}{3}} \quad (2)$$

$$r_i = \sqrt[3]{y} \quad (3)$$

$$V = \int_0^1 \pi \left( 1^2 - \sqrt[3]{y^2} \right) dy \quad (4)$$

$$= \int_0^1 \pi \left( 1 - y^{\frac{2}{3}} \right) dy \quad (5)$$

$$= \frac{2}{5} \pi \quad (6)$$

25. Which solid of rotation is bigger

$$y = x^2$$

$$y = \sqrt{8x}$$

$$x^2 = \sqrt{8x} \quad (1)$$

$$x^4 = 8x \quad (2)$$

$$0 = x^4 - 8x \quad (3)$$

$$= x(x^3 - 8) \quad (4)$$

$$x = 0, 2 \quad (5)$$

$$y = 0, 4 \quad (6)$$

$$r_o = \sqrt{8x} \quad (7)$$

$$r_i = x^2 \quad (8)$$

$$V = \int_0^2 \pi \left( \sqrt{8x^2} - (x^2)^2 \right) dx \quad (9)$$

$$= \int_0^2 \pi (8x - x^4) dx \quad (10)$$

$$= \frac{48}{5} \pi \quad (11)$$

$$r_o = \sqrt{y} \quad (12)$$

$$r_i = \frac{y^2}{8} \quad (13)$$

$$V = \int_0^4 \pi \left( \sqrt{y^2} - \left( \frac{y^2}{8} \right)^2 \right) dy \quad (14)$$

$$= \int_0^4 \pi \left( y - \frac{y^4}{64} \right) dy \quad (15)$$

$$= \frac{24}{5} \pi \quad (16)$$

26. Volume and rotation about a parallel axis

$$x = 0$$

$$y = \sqrt{x}$$

$$y = 2$$

$$x = 4 \quad (\text{about})$$

$$x = y^2 \quad (1)$$

$$r_o = 4 \quad (2)$$

$$r_i = 4 - y^2 \quad (3)$$

$$V = \int_0^2 \pi \left( 4^2 - (4 - y^2)^2 \right) dy \quad (4)$$

$$= \int_0^2 \pi (8y^2 - y^4) dy \quad (5)$$

$$= \frac{224}{15} \pi \quad (6)$$

27. Applying the cylindrical shells formula ( $y$ -axis)

$$y = -x^2 + 4x + 2$$

$$y = x^2 - 6x + 10$$

$$\text{Axis: } y$$

$$h = -x^2 + 4x + 2 - (x^2 - 6x + 10) \quad (1)$$

$$= -2x^2 + 10x - 8 \quad (2)$$

$$x = 1, 4 \quad (3)$$

$$V = \int_1^4 2\pi x (-2x^2 + 10x - 8) dx \quad (4)$$

$$= 45\pi \quad (5)$$

28. Applying the cylindrical shells formula ( $x$ -axis)

$$y = x^3$$

$$y = 1$$

$$x = 0$$

Axis:  $x$

$$r = y \quad (1)$$

$$y = x^3 \quad (2)$$

$$x = \sqrt[3]{y} \quad (3)$$

$$h = x \quad (4)$$

$$= \sqrt[3]{y} \quad (5)$$

$$V = \int_0^1 2\pi y \sqrt[3]{y} dy \quad (6)$$

$$= \int_0^1 2\pi y^{\frac{4}{3}} dy \quad (7)$$

$$= \frac{6}{7}\pi \quad (8)$$

29. Applying the cylindrical shells formula (parallel line)

$$y = x^2$$

$$y = 1$$

$$x = 0$$

(a)  $x = -1$

$$r = x + 1 \quad (1)$$

$$h = 1 - x^2 \quad (2)$$

$$V = \int_0^1 2\pi (x + 1) (1 - x^2) dx \quad (3)$$

$$= \frac{11}{6}\pi \quad (4)$$

(b)  $y = 6$

$$r = 6 - y \quad (1)$$

$$y = x^2 \quad (2)$$

$$x = \sqrt{y} \quad (3)$$

$$h = x \quad (4)$$

$$= \sqrt{y} \quad (5)$$

$$V = \int_0^1 2\pi (6 - y) \sqrt{y} dy \quad (6)$$

$$= \frac{36}{5}\pi \quad (7)$$

30. Using both the disk/washer and shells method

$$y = 8$$

$$y = 2x + 2$$

$$x = 0$$

$$x = 2$$

Axis:  $y$

(a) Disk/Washer Method

$$r_i = 0 \quad (1)$$

$$r_o = 2 \quad (2)$$

$$y = 2x + 2 \quad (3)$$

$$x = \frac{y-2}{2} \quad (4)$$

$$r_o = \frac{y-2}{2} \quad (5)$$

$$V = \int_2^6 \left( \frac{y-2}{2} \right)^2 dy + \int_6^8 \pi (2)^2 dy \quad (6)$$

$$= \frac{40}{3} \pi \quad (7)$$

(b) Cylindrical Shells

$$r = x \quad (1)$$

$$h = 8 - (2x + 2) \quad (2)$$

$$= 6 - 2x \quad (3)$$

$$V = \int_0^2 2\pi x (6 - 2x) dy \quad (4)$$

$$= \frac{40}{3} \pi \quad (5)$$

## Related Exercises

1. (Section 5.4, Exercise 15)

$$\int_{-2}^2 (x^2 + x^3) dx = \int_{-2}^2 x^2 dx + \int_{-2}^2 x^3 dx \quad (1)$$

$$= 2 \int_0^2 x^2 dx + 0 \quad (2)$$

$$= 2 \frac{x^3}{3} \quad (3)$$

$$= 2 \frac{2^3}{3} - 2 \frac{0^3}{3} \quad (4)$$

$$= 2 \frac{8}{3} \quad (5)$$

$$= \frac{16}{3} \quad (6)$$

2. (Section 5.4, Exercise 16)

$$\int_{-\pi}^{\pi} t^2 \sin t dx = 0$$

3. (Section 5.4, Exercise 26)

$$f(x) = x^2 + 1$$
$$[-2, 2]$$

$$\bar{f} = \frac{1}{2 - (-2)} \int_{-2}^2 x^2 + 1 \, dx \quad (1)$$

$$= \frac{1}{4} \left( \int_{-2}^2 x^2 \, dx + 1 \int_{-2}^2 x^0 \, dx \right) \quad (2)$$

$$= \frac{1}{4} \left( \frac{x^3}{3} + x \right) \quad (3)$$

$$= \frac{1}{4} \left( \int_{-2}^2 x^2 \, dx + \int_{-2}^2 1 \, dx \right) \quad (4)$$

$$= \frac{1}{4} \left( \frac{2^3}{3} - \frac{(-2)^3}{3} + 2 - (-2) \right) \quad (5)$$

$$= \frac{1}{4} \left( \frac{8}{3} - \frac{-8}{3} + 4 \right) \quad (6)$$

$$= \frac{1}{4} \left( \frac{16}{3} + 4 \right) \quad (7)$$

$$= \frac{1}{4} \left( \frac{28}{3} \right) \quad (8)$$

$$= \frac{7}{3} \quad (9)$$

4. (Section 5.4, Exercise 34)

$$f(x) = x^3 - 5x^2 + 30$$

$$[0, 4]$$

$$\bar{f} = \frac{1}{4} \left( \int_0^4 (x^3 - 5x^2 + 30) \, dx \right) \quad (1)$$

$$= \frac{1}{4} \left( \int_0^4 x^3 - 5 \int_0^4 x^2 + 30 \int_0^4 x^0 \right) \quad (2)$$

$$= \frac{1}{4} \left( \frac{x^4}{4} - 5 \frac{x^3}{3} + 30x \right) \quad (3)$$

$$= \frac{1}{4} \left( \left( \frac{4^4}{4} - \frac{0^4}{4} \right) - \left( 5 \frac{4^3}{3} - 5 \frac{0^3}{3} \right) + (30(4) - 30(0)) \right) \quad (4)$$

$$= \frac{1}{4} \left( 64 - \frac{320}{3} + 120 \right) \quad (5)$$

$$= \frac{1}{4} \left( \frac{232}{3} \right) \quad (6)$$

$$= \frac{58}{3} \quad (7)$$

5. (Section 5.4, Exercise 41)

$$f(x) = 1 - \frac{x^2}{a^2}$$

$$[0, a]$$



$$\bar{f} = \frac{1}{a} \left( \int_0^a 1 - \frac{x^2}{a^2} dx \right) \quad (1)$$

$$= \frac{1}{a} \left( \int_0^a 1 dx - \int_0^a \frac{x^2}{a^2} dx \right) \quad (2)$$

$$= \frac{1}{a} \left( x - \frac{1}{a^2} \int_0^a x^2 dx \right) \quad (3)$$

$$= \frac{1}{a} \left( x - \frac{1}{a^2} \frac{x^3}{3} \right) \quad (4)$$

$$= \frac{1}{a} \left( x - \frac{x^3}{3a^2} \right) \quad (5)$$

$$= \frac{1}{a} \left( (a - 0) - \frac{1}{a^2} \left( \frac{a^3}{3} - \frac{0^3}{3} \right) \right) \quad (6)$$

$$= \frac{1}{a} \left( a - \frac{a^3}{3a^2} \right) \quad (7)$$

$$= \frac{1}{a} \left( a - \frac{a}{3} \right) \quad (8)$$

$$= \frac{1}{a} \left( \frac{2a}{3} \right) \quad (9)$$

$$= \frac{2}{3} \quad (10)$$

$$1 - \frac{c^2}{a^2} = \frac{2}{3} \quad (11)$$

$$\frac{c^2}{a^2} = \frac{1}{3} \quad (12)$$

$$c^2 = \frac{a^2}{3} \quad (13)$$

$$c = \sqrt{\frac{a^2}{3}} \quad (14)$$

$$= \frac{a}{\sqrt{3}} \quad (15)$$

6. (Section 5.4, Exercise 42)

$$f(x) = \frac{\pi}{4} \sin x$$

$$[0, \pi]$$

$$\bar{f} = \frac{1}{\pi} \int_0^\pi \frac{\pi}{4} \sin x \quad (1)$$

$$= \frac{1}{\pi} \frac{\pi}{4} \int_0^\pi \sin x \quad (2)$$

$$= \frac{1}{\pi} \frac{\pi}{4} (-\cos x) \quad (3)$$

$$= \frac{1}{\pi} \frac{\pi}{4} (-\cos \pi + \cos 0) \quad (4)$$

$$= \frac{1}{\pi} \frac{\pi}{4} (1 + 1) \quad (5)$$

$$= \frac{1}{\pi} \frac{\pi}{2} \quad (6)$$

$$= \frac{1}{2} \quad (7)$$

$$\frac{\pi}{4} \sin x = \frac{1}{2} \quad (8)$$

$$\sin x = \frac{2}{\pi} \quad (9)$$

$$\sin^{-1} \sin x = \sin^{-1} \frac{2}{\pi} \quad (10)$$

$$x = \sin^{-1} \frac{2}{\pi} \quad (11)$$

7. (Section 5.5, Exercise 17)

$$u = x^2 - 1 \quad (1)$$

$$du = 2x \, dx \quad (2)$$

$$\int 2x (x^2 - 1)^{99} \, dx = \int u^{99} \, du \quad (3)$$

$$= \frac{u^{100}}{100} + C \quad (4)$$

$$= \frac{(x^2 - 1)^{100}}{100} + C \quad (5)$$

8. (Section 5.5, Exercise 20)

$$u = \sqrt{x} + 1 \quad (1)$$

$$du = \frac{1}{2\sqrt{x}} \, dx \quad (2)$$

$$\int \frac{(\sqrt{x} + 1)^4}{2\sqrt{x}} \, dx = \int u^4 \, du \quad (3)$$

$$= \frac{u^5}{5} + C \quad (4)$$

$$= \frac{(\sqrt{x} + 1)^5}{5} + C \quad (5)$$

9. (Section 5.5, Exercise 21)

$$u = x^2 + x \quad (1)$$

$$du = (2x + 1) \, dx \quad (2)$$

$$\int (x^2 + x)^{10} (2x + 1) \, dx = \int u^{10} \, du \quad (3)$$

$$= \frac{u^{11}}{11} + C \quad (4)$$

$$= \frac{(x^2 + x)^{11}}{11} + C \quad (5)$$

10. (Section 5.5, Exercise 23)

$$u = x^4 + 16 \quad (1)$$

$$du = 4x^3 \, dx \quad (2)$$

$$x^3 \, dx = \frac{1}{4} \, du \quad (3)$$

$$\int x^3 (x^4 + 16)^6 \, dx = \int \frac{1}{4} u^6 \, du \quad (4)$$

$$= \frac{1}{4} \int u^6 \, du \quad (5)$$

$$= \frac{1}{4} \cdot \frac{u^7}{7} + C \quad (6)$$

$$= \frac{(x^4 + 16)^7}{28} + C \quad (7)$$

11. (Section 5.5, Exercise 24)

$$u = \sin \theta \quad (1)$$

$$du = \cos \theta \, d\theta \quad (2)$$

$$\int \sin^{10} \theta \cos \theta \, d\theta = \int u^{10} \, du \quad (3)$$

$$= \frac{u^{11}}{11} + C \quad (4)$$

$$= \frac{\sin^{11} \theta}{11} + C \quad (5)$$

12. (Section 5.5, Exercise 78)

$$u = x - 2 \quad (1)$$

$$x = u + 2 \quad (2)$$

$$du = dx \quad (3)$$

$$\int \frac{x}{x-2} dx = \int \frac{u+2}{u} du \quad (4)$$

$$= \int \frac{u}{u} du + \int \frac{2}{u} du \quad (5)$$

$$= u + 2 \int \frac{1}{u} du + C \quad (6)$$

$$= u + 2 \ln |u| + C \quad (7)$$

$$= x - 2 + 2 \ln |u| + C \quad (8)$$

13. (Section 5.5, Exercise 79)

$$u = \sqrt{x-4} \quad (1)$$

$$u^2 = x - 4 \quad (2)$$

$$x = u^2 + 4 \quad (3)$$

$$dx = 2u du \quad (4)$$

$$\int \frac{x}{\sqrt{x-4}} dx = \int 2u \frac{u^2+4}{u} du \quad (5)$$

$$= \int \frac{2u^3+8u}{u} du \quad (6)$$

$$= 2 \left( \int u^2 du + \int 4 du \right) \quad (7)$$

$$= 2 \left( \frac{\sqrt{x-4}^3}{3} + 4\sqrt{x-4} \right) + C \quad (8)$$

$$= \frac{2}{3} \sqrt{x-4} + 8\sqrt{x-4} + C \quad (9)$$

14. (Section 5.5, Exercise 15)

$$\int e^{10x} dx = \frac{1}{10} e^{10x} + C \quad (1)$$

$$\int \sec 5x \tan 5x dx = \frac{1}{5} \sec 5x + C \quad (2)$$

$$\int \sin 7x dx = -\frac{1}{7} \cos 7x + C \quad (3)$$

$$\int \cos \frac{x}{7} dx = 7 \sin \frac{x}{7} + C \quad (4)$$

$$\int \frac{dx}{81+9x^2} = \int \frac{dx}{9^2+9x^2} \quad (5)$$

$$= \int \frac{dx}{9(9+x^2)} \quad (6)$$

$$= \frac{1}{9} \int \frac{dx}{3^2+x^2} \quad (7)$$

$$= \frac{1}{27} \tan^{-1} \frac{x}{3} + C \quad (8)$$

$$\int \frac{dx}{\sqrt{36-x^2}} = \int \frac{dx}{\sqrt{6^2-x^2}} \quad (9)$$

$$= \sin^{-1} \frac{x}{6} + C \quad (10)$$

15. (Section 5.5, Exercise 16)

$$\int_0^1 10^x dx = \frac{1}{\ln 10} 10 - \frac{1}{\ln 10} \quad (1)$$

$$= \frac{9}{\ln 10} \quad (2)$$

$$\int_0^{\frac{\pi}{40}} \cos 20x dx = \cos \frac{20\pi}{40} - \cos 20(0) \quad (3)$$

$$= 0 - 1 \quad (4)$$

$$= -1 \quad (5)$$

$$\int_{3\sqrt{2}}^6 \frac{dx}{x\sqrt{x^2-9}} = \int_{3\sqrt{2}}^6 \frac{dx}{x\sqrt{x^2-3^2}} \quad (6)$$

$$= \frac{1}{3} \sec^{-1} \left| \frac{6}{3} \right| - \frac{1}{3} \sec^{-1} \left| \frac{3\sqrt{2}}{3} \right| \quad (7)$$

$$= \frac{1}{3} \sec^{-1} \frac{\pi}{3} - \frac{1}{3} \sec^{-1} \frac{\pi}{4} \quad (8)$$

$$\int_0^{\frac{\pi}{16}} \sec^2 4x dx = \frac{1}{4} \tan \frac{4\pi}{16} - \frac{1}{4} \tan 0 \quad (9)$$

$$= \frac{1}{4} - 0 \quad (10)$$

$$= \frac{1}{4} \quad (11)$$

16. (Section 5.5, Exercise 49)

$$u = 2^x + 4 \quad (1)$$

$$du = 2^x \ln 2 dx \quad (2)$$

$$2^x dx = \frac{1}{\ln 2} du \quad (3)$$

$$\int_1^3 \frac{2^x}{2^x + 4} dx = \frac{1}{\ln 2} \int_6^{12} \frac{1}{u} du \quad (4)$$

$$= \frac{1}{\ln 2} (\ln 12 - \ln 6) \quad (5)$$

$$= \frac{1}{\ln 2} \cdot \ln 2 \quad (6)$$

$$= 1 \quad (7)$$

17. (Section 5.5, Exercise 51)

$$u = \sin \theta \quad (1)$$

$$du = \cos \theta d\theta \quad (2)$$

$$\int_0^{\frac{\pi}{2}} \sin^2 \theta \cos \theta d\theta = \int_0^{\frac{\pi}{2}} u^2 du \quad (3)$$

$$= \int_0^1 u^2 du \quad (4)$$

$$= \frac{1^3}{3} - \frac{0^3}{3} \quad (5)$$

$$= \frac{1}{3} \quad (6)$$

18. (Section 5.5, Exercise 64)

$$u = 3 + 2e^x \quad (1)$$

$$du = 2e^x dx \quad (2)$$

$$e^x dx = \frac{1}{2} du \quad (3)$$

$$\int_0^{\ln 4} \frac{e^x}{3 + 2e^x} dx = \frac{1}{2} \int_{u=5}^{u=11} \frac{1}{u} du \quad (4)$$

$$= \frac{\ln 11 - \ln 5}{2} \quad (5)$$

19. (Section 5.5, Exercise 87)

$$u = 2x \quad (1)$$

$$du = 2 dx \quad (2)$$

$$dx = \frac{1}{2} du \quad (3)$$

$$\cos^2 x = \frac{1 + \cos 2x}{2} \quad (4)$$

$$\int_{-\pi}^{\pi} \cos^2 x dx = \int_{-\pi}^{\pi} \frac{1}{2} + \frac{\cos 2x}{2} dx \quad (5)$$

$$= \frac{1}{2} \int_{-\pi}^{\pi} 1 + \cos 2x dx \quad (6)$$

$$= \frac{1}{2} \left( \int_{-\pi}^{\pi} 1 dx + \frac{1}{2} \int_{-\pi}^{\pi} \cos u du \right) \quad (7)$$

$$= \frac{1}{2} \left( (\pi - (-\pi)) + \frac{1}{2} \int_{u=-2\pi}^{u=2\pi} \cos u du \right) \quad (8)$$

$$= \frac{1}{2} \left( 2\pi + \frac{1}{2} (\sin 2\pi - \sin (-2\pi)) \right) \quad (9)$$

$$= \frac{1}{2} \left( 2\pi + \frac{1}{2} (0) \right) \quad (10)$$

$$= \frac{2\pi}{2} \quad (11)$$

$$= \pi \quad (12)$$

20. (Section 5.5, Exercise 91)

$$u = 4\theta \quad (1)$$

$$du = 4 d\theta \quad (2)$$

$$d\theta = \frac{1}{4} du \quad (3)$$

$$\sin^2 x = \frac{1 - \cos 2x}{2} \quad (4)$$

$$\sin^2 2\theta = \frac{1 - \cos 4\theta}{2} \quad (5)$$

$$\int_{-\pi}^{\pi} \sin^2 2\theta d\theta = \int_{-\pi}^{\pi} \frac{1 - \cos 4\theta}{2} d\theta \quad (6)$$

$$= \int_{-\pi}^{\pi} \frac{1}{2} - \frac{\cos u}{2} d\theta \quad (7)$$

$$= \frac{1}{2} \int_{-\pi}^{\pi} 1 - \cos u d\theta \quad (8)$$

$$= \frac{1}{2} \left( \int_{-\pi}^{\pi} 1 d\theta - \int_{-\pi}^{\pi} \cos u d\theta \right) \quad (9)$$

$$= \frac{1}{2} \left( 2\pi - \frac{1}{4} \int_{u=-4\pi}^{u=4\pi} \cos u du \right) \quad (10)$$

$$= \frac{1}{2} \left( 2\pi - \frac{1}{4} (\sin 4\pi - \sin (-4\pi)) \right) \quad (11)$$

$$= \frac{2\pi}{2} \quad (12)$$

$$= \pi \quad (13)$$

21. (Section 6.1, Exercise 7)

(a)  $0 < t < 1$  and  $3 < t < 5$

(b)  $-4$

(c)  $26$

(d)  $6$

22. (Section 6.1, Exercise 8)

(a)  $0 < t < 2$  and  $4 < t < 6$

(b)  $4$

(c)  $44$

(d)  $-10$

23. (Section 6.1, Exercise 17)

$$v(t) = \sin t$$

$$s(0) = 1$$

$$s(t) = 1 + \int_0^t \sin t dt \quad (1)$$

$$= 1 - \cos t + \cos 0 \quad (2)$$

$$= 2 - \cos t \quad (3)$$

24. (Section 6.1, Exercise 20)

$$v(t) = 3 \sin \pi t$$

$$s(0) = 1$$

$$u = \pi t \quad (1)$$

$$du = \pi dt \quad (2)$$

$$s(t) = 1 + \int_0^t 3 \sin \pi t dt \quad (3)$$

$$= 1 + \frac{3}{\pi} \int_0^t \sin u du \quad (4)$$

$$= 1 + \frac{3}{\pi} (-\cos \pi t + \cos 0) \quad (5)$$

$$= 1 + \frac{3}{\pi} - \frac{3}{\pi} \cos \pi t \quad (6)$$

25. (Section 6.1, Exercise 27)

$$\int_0^{20} 3t dt + \int_{20}^{30} 60 = \left( \frac{3(20)^2}{2} - \frac{3(0)^2}{2} \right) + (60(30) - 60(20)) \quad (1)$$

$$= \left( \frac{1200}{2} \right) + (1800 - 1200) \quad (2)$$

$$= 600 + 600 \quad (3)$$

$$= 1200 \quad (4)$$

$$\int_0^{20} 3t dt + \int_{20}^{45} 60 + \int_{45}^{60} 240 - 4t dt = 600 + 2700 - 1200 + 14400 - 7200 - 10800 - 4050 \quad (5)$$

$$= 2100 + ((14400 - 7200) - (10800 - 4050)) \quad (6)$$

$$= 2100 + (7200 - 6750) \quad (7)$$

$$= 2550 \quad (8)$$

$$s(t) = \int_0^{20} 3t dt + \int_{20}^{45} 60 + \int_{45}^t 240 - 4t dt \quad (9)$$

$$= 2100 + (240t - 2t^2 - 6750) \quad (10)$$

$$= 240t - 2t^2 - 4650 \quad (11)$$

$$s(75) = 2100 \quad (12)$$

26. (Section 6.1, Exercise 28)

$$\int_0^{10} 9.8t dt + \int_{10}^{30} 10 = (4.9(10)^2 - 4.9(0^2)) + (10(30) - 10(10)) \quad (1)$$

$$= (4.9(100)) + (300 - 100) \quad (2)$$

$$= 490 + 200 \quad (3)$$

$$= 690 \quad (4)$$

27. (Section 6.1, Exercise 30)

$$a(t) = -32$$

$$v(0) = 50$$

$$s(0) = 0$$

$$v(t) = v(0) + \int_0^t -32 \quad (1)$$

$$= 50 - 32t \quad (2)$$

$$s(t) = s(0) + \int_0^t 50 - 32t \quad (3)$$

$$= 50t - 16t^2 \quad (4)$$

28. (Section 6.1, Exercise 31)

$$a(t) = -9.8$$

$$v(0) = 20$$

$$s(0) = 0$$

$$v(t) = v(0) + \int_0^t -9.8 \quad (1)$$

$$= 20 - 9.8t \quad (2)$$

$$s(t) = s(0) + \int_0^t 20 - 9.8t \quad (3)$$

$$= 20t - 4.9t^2 \quad (4)$$

29. (Section 6.1, Exercise 43)

$$N'(t) = 100e^{-0.25t}$$

$$u = -0.25t \quad (1)$$

$$du = -0.25 dt \quad (2)$$

$$N(t) = N(0) + \int_0^t 10e^{-0.25t} dt \quad (3)$$

$$= 1900 + 100 \int_0^t \frac{1}{-0.25} e^u du \quad (4)$$

$$= 1900 - 400e^{-0.25t} \quad (5)$$

$$N(20) = 1900 - 400e^{-5} \quad (6)$$

$$\approx 1897.305 \quad (7)$$

$$N(40) = 1900 - 400e^{-10} \quad (8)$$

$$\approx 1899.98 \quad (9)$$

30. (Section 6.1, Exercise 44)

$$r(t) = 0.0025e^{0.25t} - 0.1485e^{-0.15t}$$

$$t_0 = \frac{\ln 0.0025 - \ln 0.1485}{-0.4} \quad (1)$$

$$\int_0^{t_0} 0.0025e^{0.25t} - 0.1485e^{-0.15t} \approx 271 \quad (2)$$

31. (Section 6.1, Exercise 55)

$$C'(x) = 2000 - 0.5x$$

$$\int_{100}^{150} 2000 - 0.5x dx = (2000(150) - 0.25(150)^2) - (2000(100) - 0.25(100)^2) \quad (1)$$

$$= (300000 - 5625) - (200000 - 2500) \quad (2)$$

$$= 294375 - 197500 \quad (3)$$

$$= 96875 \quad (4)$$

$$\int_{500}^{550} 2000 - 0.5x dx = (1024375) - (937500) \quad (5)$$

$$= 86875 \quad (6)$$

32. (Section 6.1, Exercise 56)

$$C'(x) = 200 - 0.05x$$

$$\int_{100}^{150} 200 - 0.05x dx = (200(150) - 0.025(150)^2) - (200(100) - 0.025(100)^2) \quad (1)$$

$$= (29437.5) - (19750) \quad (2)$$

$$= 9687.5 \quad (3)$$

$$\int_{500}^{550} 200 - 0.05x dx = (200(550) - 0.025(550)^2) - (200(500) - 0.025(500)^2) \quad (4)$$

$$= 102437.5 - 93750 \quad (5)$$

$$= 8687.5 \quad (6)$$



33. (Section 6.2, Exercise 9)

$$y = x$$

$$y = x^2 - 2$$

$$x = x^2 - 2 \quad (1)$$

$$0 = x^2 - x - 2 \quad (2)$$

$$= (x+1)(x-2) \quad (3)$$

$$x = -1, 2 \quad (4)$$

$$\int_{-2}^1 (-x^2 + x + 2) dx = \left( -\frac{2^3}{3} + \frac{2^2}{2} + 2(2) \right) - \left( -\frac{(-1)^3}{3} + \frac{(-1)^2}{2} + 2(-1) \right) \quad (5)$$

$$= \left( -\frac{8}{3} + \frac{4}{2} + 4 \right) - \left( \frac{1}{3} + \frac{1}{2} - 2 \right) \quad (6)$$

$$= -\frac{8}{3} + \frac{4}{2} + 4 - \frac{1}{3} - \frac{1}{2} + 2 \quad (7)$$

$$= -\frac{9}{3} + \frac{3}{2} + 6 \quad (8)$$

$$= -3 + \frac{3}{2} + 6 \quad (9)$$

$$= \frac{3}{2} + 3 \quad (10)$$

$$= 4.5 \quad (11)$$

34. (Section 6.2, Exercise 10)

$$y = -x^2 + 4x$$

$$y = x^2 - 2x$$

$$-x^2 + 4x = x^2 - 2x \quad (1)$$

$$0 = 2x^2 - 6x \quad (2)$$

$$= 2x(x-3) \quad (3)$$

$$x = 0, 3 \quad (4)$$

$$\int_0^6 (-x^2 + 4x - x^2 + 2x) dx = \left( \frac{-2(6)^3}{3} + 3(6)^2 \right) \quad (5)$$

$$= \left( \frac{-2(216)}{3} + 3(36) \right) \quad (6)$$

$$= \left( \frac{-432}{3} + 108 \right) \quad (7)$$

$$= -144 + 108 \quad (8)$$

$$= -36 \quad (9)$$

35. (Section 6.2, Exercise 15)

$$y = \sin x$$

$$y = \cos x$$

$$\sin x = \cos x \quad (1)$$

$$0 = \sin x - \cos x \quad (2)$$

$$x = \frac{\pi}{4} \quad (3)$$

$$\int_0^{\frac{\pi}{4}} \sin x dx + \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \cos x dx = \left( -\cos \frac{\pi}{4} + \cos 0 \right) + \left( \sin \frac{\pi}{2} - \sin \frac{\pi}{4} \right) \quad (4)$$

$$= \left( -\frac{1}{\sqrt{2}} + 1 \right) + \left( 1 - \frac{1}{\sqrt{2}} \right) \quad (5)$$

$$= 2 - \sqrt{2} \quad (6)$$

36. (Section 6.2, Exercise 16)

$$y = x^3$$

$$y = x$$

$$x^3 = x \quad (1)$$

$$0 = x^3 - x \quad (2)$$

$$= x(x^2 - 1) \quad (3)$$

$$x = -1, 0, 1 \quad (4)$$

$$\int_{-1}^0 (x^3 - x) dx + \int_0^1 (x - x^3) dx = -\left(\frac{(-1)^4}{4} - \frac{(-1)^2}{2}\right) + \left(\frac{1^2}{2} - \frac{1^4}{4}\right) \quad (5)$$

$$= -\left(\frac{1}{4} - \frac{1}{2}\right) + \left(\frac{1}{2} - \frac{1}{4}\right) \quad (6)$$

$$= \frac{1}{4} + \frac{1}{4} \quad (7)$$

$$= \frac{1}{2} \quad (8)$$

37. (Section 6.2, Exercise 19)

$$x = y^2 - 3$$

$$x = 2y$$

$$2y = y^2 - 3 \quad (1)$$

$$0 = y^2 - 2y - 3 \quad (2)$$

$$= (y - 3)(y + 1) \quad (3)$$

$$y = -1, 3 \quad (4)$$

$$\int_{-1}^3 (2y - y^2 + 3) dy = \left(3^2 - \frac{3^3}{3} + 3(3)\right) - \left((-1)^2 - \frac{(-1)^3}{3} + 3(-1)\right) \quad (5)$$

$$= \left(9 - \frac{27}{3} + 9\right) - \left(1 - \frac{-1}{3} - 3\right) \quad (6)$$

$$= (18 - 9) - \left(-2 + \frac{1}{3}\right) \quad (7)$$

$$= 9 + 2 - \frac{1}{3} \quad (8)$$

$$= 11 - \frac{1}{3} \quad (9)$$

$$= \frac{32}{3} \quad (10)$$

38. (Section 6.2, Exercise 20)

$$x = \frac{y}{4}$$

$$x = \sqrt{y}$$

$$\int_0^4 \left(\sqrt{y} - \frac{y}{4}\right) dy = \left(\frac{2}{3} 4^{\frac{3}{2}} - \frac{4^2}{8}\right) \quad (1)$$

$$= \left(\frac{2}{3} \cdot 8 - \frac{16}{8}\right) \quad (2)$$

$$= \frac{16}{3} - 2 \quad (3)$$

$$= \frac{10}{3} \quad (4)$$

39. (Section 6.2, Exercise 34)

$$y = 2x^2$$

$$y = 3 - x$$

$$2x^2 = 3 - x \quad (1)$$

$$0 = 2x^2 + x - 3 \quad (2)$$

$$= (2x + 3)(x - 1) \quad (3)$$

$$x = 0, 1 \quad (4)$$

$$\int_0^1 3 - x - 2x^2 dx = \left(3 - \frac{1}{2} - 2\frac{1}{3}\right) \quad (5)$$

$$= \left(3 - \frac{1}{2} - \frac{2}{3}\right) \quad (6)$$

$$= \frac{11}{6} \quad (7)$$

$$A_1 = \frac{11}{6} \quad (8)$$

$$A = A_1 + A_2 \quad (9)$$

$$= \frac{9}{2} \quad (10)$$

$$A_2 = A - A_1 \quad (11)$$

$$= \frac{9}{2} - \frac{11}{6} \quad (12)$$

$$= \frac{8}{3} \quad (13)$$

40. (Section 6.3, Exercise 11)

$$y = \sqrt{1 - x^2}$$

$$S = y \quad (1)$$

$$= \sqrt{1 - x^2} \quad (2)$$

$$A(x) = S^2 \quad (3)$$

$$= y^2 \quad (4)$$

$$= 1 - x^2 \quad (5)$$

$$x = -1, 1 \quad (6)$$

$$V = \int_{-1}^1 (1 - x^2) dx \quad (7)$$

$$= \left(1 - \frac{1^3}{3}\right) - \left(-1 - \frac{(-1)^3}{3}\right) \quad (8)$$

$$= 1 - \frac{1}{3} + 1 - \frac{1}{3} \quad (9)$$

$$= 2 - \frac{2}{3} \quad (10)$$

$$= \frac{4}{3} \quad (11)$$

41. (Section 6.3, Exercise 12)

$$y = x^2$$

$$y = 2 - x^2$$

$$x^2 = 2 - x^2 \quad (1)$$

$$0 = 2 - 2x^2 \quad (2)$$

$$= 2(1 - x^2) \quad (3)$$

$$x = -1, 1 \quad (4)$$

$$S = 2 - 2x^2 \quad (5)$$

$$A(x) = S^2 \quad (6)$$

$$= (2 - 2x^2)^2 \quad (7)$$

$$V = \int_{-1}^1 ((2 - 2x^2)^2) dx \quad (8)$$

$$= \left( \frac{4(1)^5}{5} - \frac{8(1)^3}{3} + 4(1) \right) - \left( \frac{4(-1)^5}{5} - \frac{8(-1)^3}{3} + 4(-1) \right) \quad (9)$$

$$= \frac{4}{5} - \frac{8}{3} + 4 + \frac{4}{5} - \frac{8}{3} + 4 \quad (10)$$

$$= \frac{8}{5} - \frac{16}{3} + 8 \quad (11)$$

$$= \frac{64}{15} \quad (12)$$

42. (Section 6.3, Exercise 17)

$$y = 2x$$

$$y = 0$$

$$x = 3$$

Bound:  $x$

$$V = \int_0^3 \pi (2x)^2 dx \quad (1)$$

$$= \int_0^3 4\pi x^2 dx \quad (2)$$

$$= 4\pi \int_0^3 x^2 dx \quad (3)$$

$$= 4\pi \left( \frac{3^3}{3} - \frac{0^3}{3} \right) \quad (4)$$

$$= 4\pi (9) \quad (5)$$

$$= 36\pi \quad (6)$$

43. (Section 6.3, Exercise 19)

$$y = e^{-x}$$

$$y = 0$$

$$x = 0$$

$$x = \ln 4$$

Bound:  $x$

$$V = \pi \int_0^{\ln 4} e^{-2x} dx \quad (1)$$

$$= \pi \left( -\frac{e^{-2 \ln 4}}{2} + \frac{e^{-2(0)}}{2} \right) \quad (2)$$

$$= \pi \left( -\frac{\frac{1}{16}}{2} + \frac{1}{2} \right) \quad (3)$$

$$= \pi \left( -\frac{1}{32} + \frac{1}{2} \right) \quad (4)$$

$$= \frac{15}{32} \pi \quad (5)$$

44. (Section 6.3, Exercise 23)

$$y = 2\sqrt{x}$$

$$y = x$$

$$x = 2\sqrt{x} \quad (1)$$

$$0 = 2\sqrt{x} - x \quad (2)$$

$$x = 0, 4 \quad (3)$$

$$V = \int_0^4 \pi \left( (2\sqrt{x})^2 - x^2 \right) dx \quad (4)$$

$$= \pi \left( 2(4)^2 - \frac{4^3}{3} \right) \quad (5)$$

$$= \pi \left( 2(16) - \frac{64}{3} \right) \quad (6)$$

$$= \pi \left( 32 - \frac{64}{3} \right) \quad (7)$$

$$= \frac{32}{3} \pi \quad (8)$$

45. (Section 6.3, Exercise 24)

$$y = \sqrt[4]{x}$$

$$y = x$$

$$x = \sqrt[4]{x} \quad (1)$$

$$x^4 = \sqrt[4]{x}^4 \quad (2)$$

$$= x \quad (3)$$

$$0 = x^4 - x \quad (4)$$

$$= x(x^3 - 1) \quad (5)$$

$$x = 0, 1 \quad (6)$$

$$V = \pi \int_0^1 \left( \sqrt[4]{x}^2 - x^2 \right) dx \quad (7)$$

$$= \pi \left( \frac{2}{3} \cdot 1^{\frac{3}{2}} - \frac{1^3}{3} \right) \quad (8)$$

$$= \pi \left( \frac{2}{3} - \frac{1}{3} \right) \quad (9)$$

$$= \frac{\pi}{3} \quad (10)$$

46. (Section 6.3, Exercise 48)

$$y = x^2$$

$$y = \sqrt{8x}$$

$$x^2 = \sqrt{8x} \quad (1)$$

$$x^4 = 8x \quad (2)$$

$$0 = x^4 - 8x \quad (3)$$

$$= x(x^3 - 8) \quad (4)$$

$$x = 0, 2 \quad (5)$$

$$y = 0, 4 \quad (6)$$

$$r_o = \sqrt{8x} \quad (7)$$

$$r_i = x^2 \quad (8)$$

$$V = \int_0^2 \pi \left( \sqrt{8x}^2 - (x^2)^2 \right) dx \quad (9)$$

$$= \int_0^2 \pi (8x - x^4) dx \quad (10)$$

$$= \frac{48}{5} \pi \quad (11)$$

$$r_o = \sqrt{y} \quad (12)$$

$$r_i = \frac{y^2}{8} \quad (13)$$

$$V = \int_0^4 \pi \left( \sqrt{y}^2 - \left( \frac{y^2}{8} \right)^2 \right) dy \quad (14)$$

$$= \int_0^4 \pi \left( y - \frac{y^4}{64} \right) dy \quad (15)$$

$$= \frac{24}{5} \pi \quad (16)$$