

## ***Solution***

### **Section 3.2 – Arc Length & Area – Velocity**

#### ***Exercise***

The minute hand of a clock is 1.2 *cm* long. How far does the tip of the minute hand travel in 40 *minutes*?

#### **Solution**

$$\begin{aligned} 40 \text{ min} &= 40 \text{ min} \frac{2\pi}{60} \frac{\text{rad}}{\text{min}} \\ &= \frac{4\pi}{3} \text{ rad.} \end{aligned}$$

$$\begin{aligned} s &= (1.2) \frac{4\pi}{3} & s &= r\theta \\ &= \frac{(12)(4)\pi}{30} \\ &= \frac{8\pi}{5} \text{ cm} \end{aligned}$$

#### ***Exercise***

Find the radian measure of angle  $\theta$ , if  $\theta$  is a central angle in a circle of radius  $r = 4$  *inches*, and  $\theta$  cuts off an arc of length  $s = 12\pi$  *inches*.

#### **Solution**

$$\begin{aligned} \theta &= \frac{12\pi}{4} & \theta &= \frac{s}{r} \\ &= 3\pi \text{ rad} \end{aligned}$$

#### ***Exercise***

Give the length of the arc cut off by a central angle of 2 *radians* in a circle of radius 4.3 *inches*

#### **Solution**

$$\text{Given: } \theta = 2 \text{ rad, } r = 4.3 \text{ in}$$

$$\begin{aligned} s &= 4.3(2) & s &= r\theta \\ &= 8.6 \text{ in} \end{aligned}$$

### Exercise

A space shuttle 200 *miles* above the earth is orbiting the earth once every 6 *hours*. How long, in hours, does it take the space shuttle to travel 8,400 *miles*? (Assume the radius of the earth is 4,000 *miles*.) Give both the exact value and an approximate value for your answer.

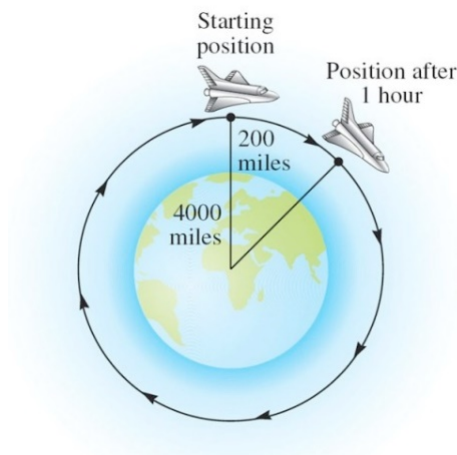
### Solution

$$\theta = \frac{8400}{4200}$$
$$= 2 \text{ rad}$$

$$\theta = \frac{s}{r}$$

$$\frac{2 \text{ rad}}{2\pi \text{ rad}} = \frac{x \text{ hr}}{6 \text{ hr}}$$

$$x = \frac{2(6)}{2\pi}$$
$$= \frac{6}{\pi} \text{ hrs}$$
$$\approx 1.91 \text{ hrs}$$



### Exercise

The pendulum on a grandfather clock swings from side to side once every second. If the length of the pendulum is 4 *feet* and the angle through which it swings is  $20^\circ$ . Find the total distance traveled in 1 *minute* by the tip of the pendulum on the grandfather clock.

### Solution

$$\text{Since } 20^\circ = 20 \cdot \frac{\pi}{180}$$
$$= \frac{\pi}{9} \text{ rad}$$

The length of the pendulum swings in 1 second:

$$s = r\theta = 4 \cdot \frac{\pi}{9}$$
$$= \frac{4\pi}{9} \text{ ft}$$

In 60 seconds, the total distance traveled

$$d = 60 \cdot \frac{4\pi}{9}$$
$$= \frac{80\pi}{3} \text{ feet} \quad \approx 83.8 \text{ feet}$$

### Exercise

Reno, Nevada is due north of Los Angeles. The latitude of Reno is  $40^\circ$ , while that of Los Angeles is  $34^\circ$  N. The radius of Earth is about 4000 *mi*. Find the north-south distance between the two cities.

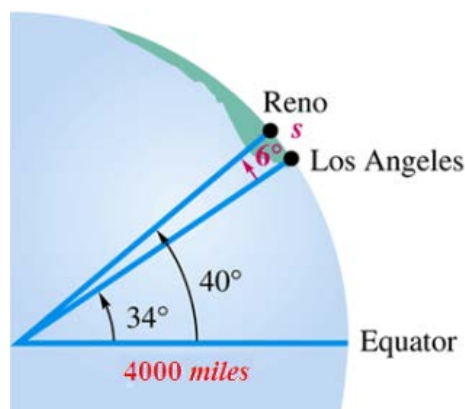
### Solution

The central angle between two cities:  $40^\circ - 34^\circ = 6^\circ$

$$6^\circ = 6 \left( \frac{\pi}{180} \right) \\ = \frac{\pi}{30} \text{ rad}$$

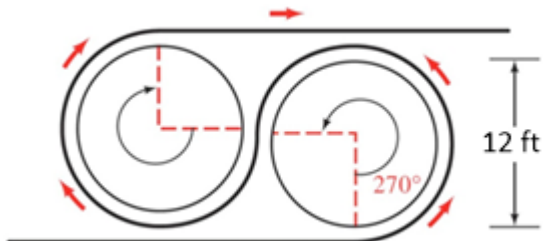
$$s = 4000 \frac{\pi}{30} \\ = \frac{400\pi}{3} \text{ miles} \\ \approx 419 \text{ miles}$$

$$s = r\theta$$



### Exercise

The first cable railway to make use of the figure-eight drive system was a Sutter Street Railway. Each drive sheave was 12 *feet* in diameter.



Find the length of cable riding on one of the drive sheaves.

### Solution

$$\text{Since } 270^\circ = 270 \cdot \frac{\pi}{180} \\ = \frac{3\pi}{2} \text{ rad}$$

The length of the cable riding on one of the drive sheaves is:

$$s = 6 \cdot \frac{3\pi}{2} \\ = 9\pi \text{ feet} \\ \approx 28.3 \text{ feet}$$

$$s = r\theta$$

## Exercise

The diameter of a model of George Ferris's Ferris wheel is 250 feet, and  $\theta$  is the central angle formed as a rider travels from his or her initial position  $P_0$  to position  $P_1$ . Find the distance traveled by the rider if  $\theta = 45^\circ$  and if  $\theta = 105^\circ$ .

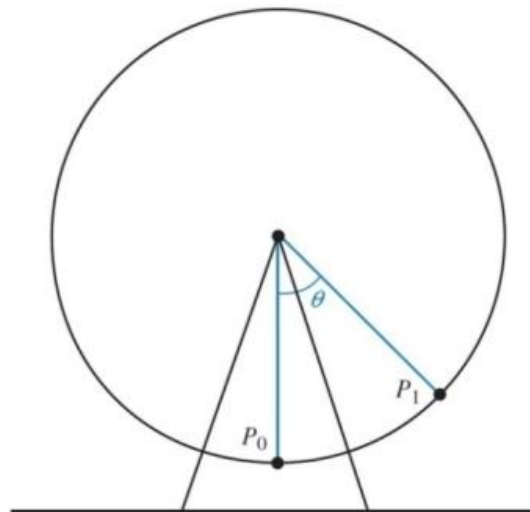
### Solution

$$r = \frac{D}{2} = \frac{250}{2} = 125 \text{ ft}$$

$$\text{For } \theta = 45^\circ = \frac{\pi}{4}$$

$$\begin{aligned} s &= 125 \left( \frac{\pi}{4} \right) \\ &= \frac{125\pi}{4} \text{ feet} \\ &\approx 98 \text{ ft} \end{aligned}$$

$$s = r\theta$$



$$\text{For } \theta = 105^\circ$$

$$= 105 \frac{\pi}{180}$$

$$= \frac{7\pi}{12}$$

$$\begin{aligned} s &= 125 \frac{7\pi}{12} \\ &= \frac{875\pi}{12} \text{ feet} \\ &\approx 230 \text{ ft} \end{aligned}$$

## Exercise

Two gears are adjusted so that the smaller gear drives the larger one. If the smaller gear rotates through an angle of  $225^\circ$ , through how many degrees will the larger gear rotate?

### Solution

$$s = r_1 \theta_1 = r_2 \theta_2$$

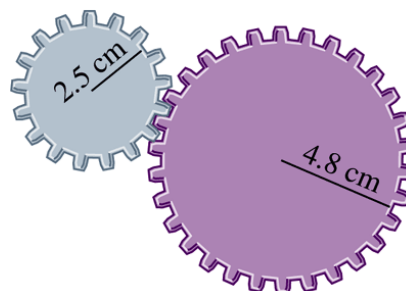
$$2.5(225^\circ) = 4.8\theta_2$$

$$\theta_2 = \frac{2.5(225^\circ)}{4.8}$$

$$= \frac{25(225^\circ)}{48}$$

$$= \left( \frac{5,625}{48} \right)^\circ$$

$$= 117.1875^\circ$$



### Exercise

If a central angle with its vertex at the center of the earth has a measure of  $1'$ , then the arc on the surface of the earth that is cut off by this angle (known as the great circle distance) has a measure of 1 *nautical mile*.

### Solution

$$\theta = 1'$$

$$= \frac{1}{60}^{\circ}$$

$$= \frac{1}{60} \cdot \frac{\pi}{180}$$

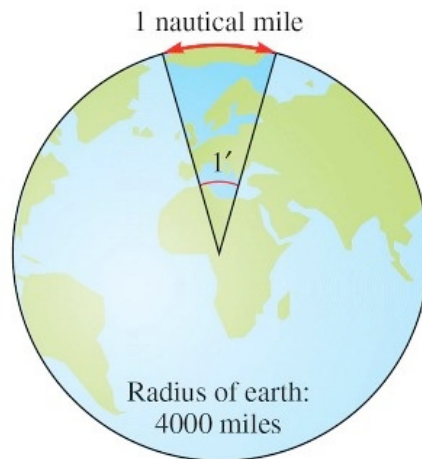
$$= \frac{\pi}{10800} \text{ rad}$$

$$\frac{\pi}{10800} = \frac{s}{4000}$$

$$s = \frac{4000}{10800} \pi$$

$$= \frac{10\pi}{27} \text{ miles} \quad \approx 1.16 \text{ mi}$$

$$\theta = \frac{s}{r}$$



### Exercise

If two ships are 20 *nautical miles* apart on the ocean, how many statute miles apart are they?

### Solution

$$\theta = 20'$$

$$= \frac{20}{60}^{\circ}$$

$$= \frac{1}{3}^{\circ}$$

$$= \frac{1}{3} \cdot \frac{\pi}{180}$$

$$= \frac{\pi}{540} \text{ rad}$$

$$\frac{\pi}{540} = \frac{s}{4000}$$

$$s = \frac{4000\pi}{540}$$

$$= \frac{200\pi}{27} \text{ miles}$$

$$s \approx 23.27 \text{ mi}$$

$$\theta = \frac{s}{r}$$

### Exercise

Two gears are adjusted so that the smaller gear drives the larger one. If the smaller gear rotates through an angle of  $300^\circ$ , through how many degrees will the larger rotate?

#### Solution

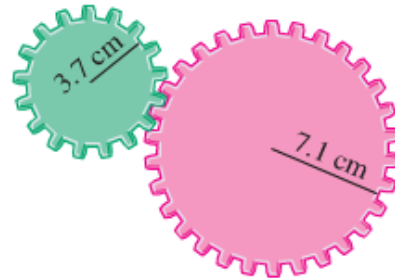
Both gears travel the same arc distance ( $s$ ), therefore:

$$s = r_1 \theta_1 = r_2 \theta_2$$

$$3.7(300^\circ) = 7.1 \theta_2$$

$$\theta_2 = \frac{37}{71}(300^\circ)$$

$$= \left( \frac{11,100}{71} \right)^\circ$$
$$\approx 156.34^\circ$$



### Exercise

The rotation of the smaller wheel causes the larger wheel to rotate. Through how many degrees will the larger wheel rotate if the smaller one rotates through  $60.0^\circ$ ?

#### Solution

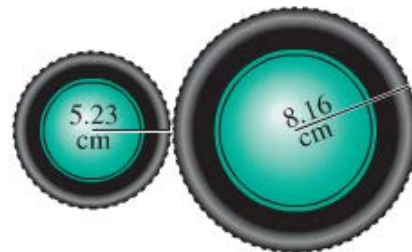
Both gears travel the same arc distance ( $s$ ), therefore:

$$s = r_1 \theta_1 = r_2 \theta_2$$

$$5.23(60.0^\circ) = 8.16 \theta_2$$

$$\theta_2 = \frac{523}{816}(60^\circ)$$

$$= \left( \frac{2,615}{68} \right)^\circ$$
$$\approx 38.5^\circ$$



### Exercise

Find the radius of the larger wheel if the smaller wheel rotates  $80^\circ$  when the larger wheel rotates  $50^\circ$ .

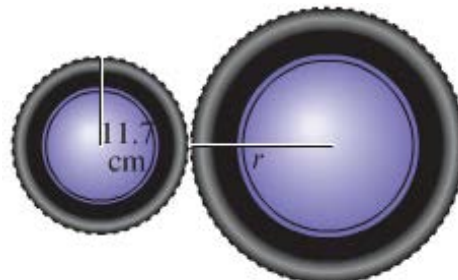
#### Solution

$$s = r_1 \theta_1 = r_2 \theta_2$$

$$11.7(80^\circ) = r_2(50^\circ)$$

$$r_2 = \frac{11.7(80^\circ)}{50^\circ}$$

$$= 18.72 \text{ cm}$$



### Exercise

How many inches will the weight rise if the pulley is rotated through an angle of  $71^\circ 50'$ ?  
Through what angle, to the nearest minute, must the pulley be rotated to raise the weight 6 in?

#### Solution

$$\theta = \left(71^\circ + 50' \frac{1^\circ}{60'}\right) \frac{\pi}{180^\circ}$$

$$s = r\theta$$

$$= 9.27 \left(71^\circ + 50' \frac{1^\circ}{60'}\right) \frac{\pi}{180^\circ}$$

$$\approx 11.622 \text{ in}$$

$$\theta = \frac{s}{r} = \frac{6}{9.27} \text{ rad}$$

$$= \frac{6}{9.27} \frac{180^\circ}{\pi}$$

$$= 37.0846^\circ$$

$$= 37^\circ + .0846(60')$$

$$\approx 37^\circ 5'$$



### Exercise

Find the radius of the pulley if a rotation of  $51.6^\circ$  raises the weight 11.4 cm.

#### Solution

$$r = \frac{s}{\theta} = \frac{11.4}{51.6^\circ \frac{\pi}{180^\circ}}$$

$$= \frac{1,710}{43\pi} \text{ cm} \approx 12.7 \text{ cm}$$



### Exercise

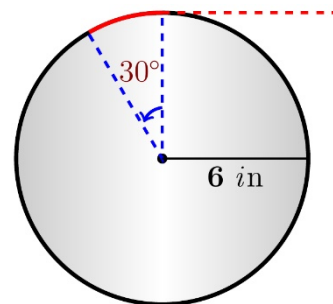
A rope is being wound around a drum with radius 6 inches. How much rope will be wound around the drum if the drum is rotated through an angle of  $30^\circ$ ?

#### Solution

$$s = 6 \left(30^\circ \frac{\pi}{180^\circ}\right)$$

$$s = r\theta$$

$$= \pi \text{ in}$$

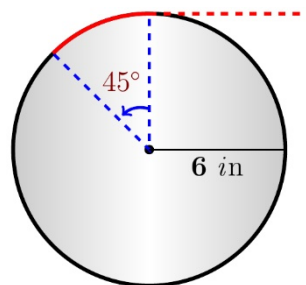


### Exercise

A rope is being wound around a drum with radius 6 inches. How much rope will be wound around the drum if the drum is rotated through an angle of  $45^\circ$ ?

#### Solution

$$\begin{aligned} s &= 6 \left( 45^\circ \frac{\pi}{180^\circ} \right) & s &= r\theta \\ &= \frac{3\pi}{2} \text{ in} \end{aligned}$$



### Exercise

The figure shows the chain drive of a bicycle. How far will the bicycle move if the pedals are rotated through  $180^\circ$ ? Assume the radius of the bicycle wheel is 13.6 in.

#### Solution

$$\theta = 180^\circ = \pi \text{ rad}$$

The distance for the pedal gear:

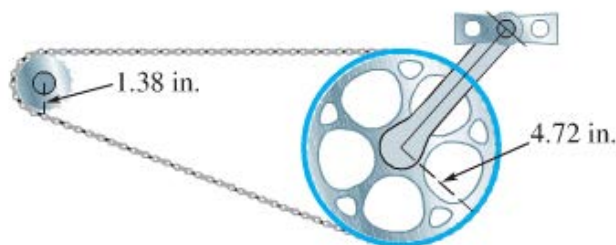
$$s = r_2 \theta = 4.72\pi$$

For the smaller gear:

$$\begin{aligned} \theta_2 &= \frac{s}{r_2} = \frac{4.72\pi}{1.38} \\ &= \frac{472\pi}{138} \\ &= \frac{236\pi}{69} \end{aligned}$$

The wheel distance:

$$\begin{aligned} s &= r_3 \theta_2 = \frac{136}{10} \left( \frac{236\pi}{69} \right) \\ &= \frac{16,048\pi}{345} \text{ in} & &= 146.12 \text{ in} \end{aligned}$$



### Exercise

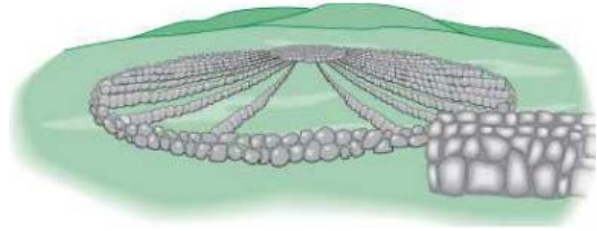
The circular of a Medicine Wheel is 2500 yrs old. There are 27 aboriginal spokes in the wheel, all equally spaced.

- Find the measure of each central angle in degrees and in radians.
- The radius measure of each of the wheel is 76.0 ft, find the circumference.
- Find the length of each arc intercepted by consecutive pairs of spokes.
- Find the area of each sector formed by consecutive spokes,

#### Solution



$$\begin{aligned}
 a) \text{ The central angle: } \theta &= \frac{360^\circ}{27} = \frac{40^\circ}{3} \\
 &= \frac{40^\circ}{3} \frac{\pi \text{ rad}}{180^\circ} \\
 &= \frac{2\pi}{27} \text{ rad}
 \end{aligned}$$



$$\begin{aligned}
 b) \quad C &= 2\pi r = 2\pi(76) \\
 &= 152\pi \text{ ft} \quad \approx 477.5 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 c) \text{ Since } r &= 76 \\
 s &= 76 \frac{2\pi}{27} \quad s = r\theta \\
 &= \frac{152\pi}{27} \text{ ft} \quad \approx 17.7 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 d) \text{ Area} &= \frac{1}{2} r^2 \theta \\
 &= \frac{1}{2} (76)^2 \frac{2\pi}{27} \\
 &= \frac{5,776\pi}{27} \text{ ft}^2 \quad \approx 672 \text{ ft}^2
 \end{aligned}$$

## Exercise

The total arm and blade of a single windshield wiper was 10 in. long and rotated back and forth through an angle of  $95^\circ$ . The shaded region in the figure is the portion of the windshield cleaned by the 7-in. wiper blade. What is the area of the region cleaned?

### Solution

The total angle:

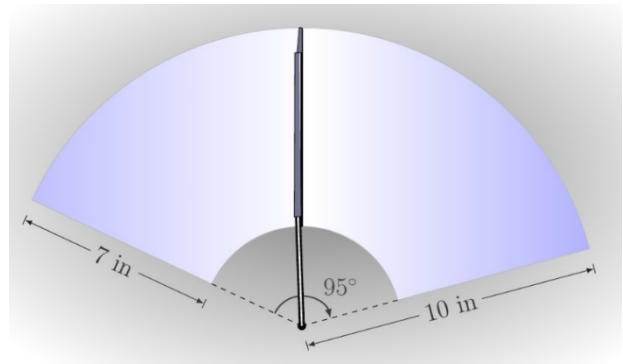
$$\begin{aligned}
 \theta &= 95^\circ \frac{\pi}{180^\circ} \\
 &= \frac{19\pi}{36} \text{ rad}
 \end{aligned}$$

$A_1$  : The area of arm only (not cleaned by the blade).

$$\begin{aligned}
 A_1 &= \frac{1}{2} (10 - 7)^2 \frac{19\pi}{36} \\
 &= \frac{19\pi}{8}
 \end{aligned}$$

$A_2$  : The area of arm and the blade.

$$\begin{aligned}
 A_2 &= \frac{1}{2} (10)^2 \frac{19\pi}{36} \\
 &= \frac{475\pi}{18}
 \end{aligned}$$



The total cleaned area:

$$\begin{aligned}
 A &= A_2 - A_1 \\
 &= \frac{475\pi}{18} - \frac{19\pi}{8} \\
 &= \frac{1900 - 171}{72} \pi \\
 &= \frac{1729\pi}{72} \text{ in}^2 \quad \quad \quad = 75.4 \text{ in}^2
 \end{aligned}$$

### Exercise

A frequent problem in surveying city lots and rural lands adjacent to curves of highways and railways is that of finding the area when one or more of the boundary lines is the arc of the circle. Find the area of the lot.

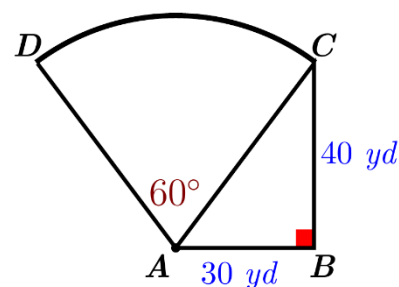
### Solution

Using the Pythagorean theorem:

$$AC = \sqrt{30^2 + 40^2} = 50 = r$$

Total area = Area of the sector (ADC) + Area of the triangle (ABC)

$$\begin{aligned}
 \text{Total area} &= \frac{1}{2} r^2 (60^\circ) \frac{\pi}{180^\circ} + \frac{1}{2} (AB)(BC) \\
 &= \frac{1}{2} 50^2 (60^\circ) \frac{\pi}{180^\circ} + \frac{1}{2} (30)(40) \\
 &= \frac{1250}{3} \pi + 600 \text{ yd}^2 \\
 &\approx 1909 \text{ yd}^2
 \end{aligned}$$



### Exercise

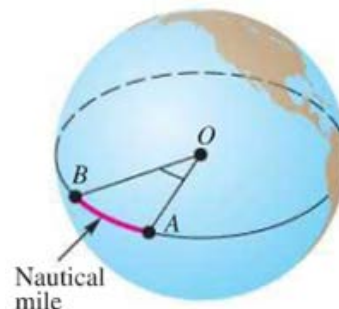
Nautical miles are used by ships and airplanes. They are different from statute miles, which equal 5280 *ft*. A nautical mile is defined to be the arc length along the equator intercepted by a central angle AOB of 1 *min*. If the equatorial radius is 3963 *mi*, use the arc length formula to approximate the number of statute miles in 1 *nautical mile*.

### Solution

$$\begin{aligned}
 \theta &= 1' \frac{1^\circ}{60'} \frac{\pi}{180^\circ} \\
 &= \frac{\pi}{10800} \text{ rad}
 \end{aligned}$$

The arc length:

$$s = 3963 \frac{\pi}{10800} \quad \quad \quad s = r\theta$$



$$= \frac{1321\pi}{3600}$$

There are  $\frac{1321\pi}{3600} \approx 1.15$  statute miles in 1 nautical mile.

### Exercise

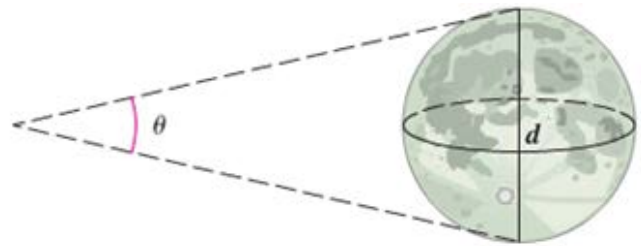
The distance to the moon is approximately 238,900 *mi*. Use the arc length formula to estimate the diameter  $d$  of the moon if angle  $\theta$  is measured to be  $0.5170^\circ$ .

### Solution

$$s = 238900 \times 0.517^\circ \frac{\pi}{180^\circ} \quad s = r\theta$$

$$= \frac{1,235,113\pi}{1800} \text{ mi}$$

$$\approx 2156 \text{ mi}$$



### Exercise

The minute hand of a clock is 1.2 *cm* long. To two significant digits, how far does the tip of the minute hand move in 20 *minutes*?

### Solution

**Given:**  $r = 1.2 \text{ cm}$

One complete rotation = 1 hour = 60 minutes =  $2\pi$

$$\frac{\theta}{2\pi} = \frac{20}{60}$$

$$\theta = \frac{2\pi}{3}$$

$$s = 1.2 \frac{2\pi}{3} \quad s = r\theta$$

$$= 12 \frac{2\pi}{30}$$

$$= \frac{4\pi}{5} \text{ cm}$$

$$\approx 2.5 \text{ cm}$$

### Exercise

If the sector formed by a central angle of  $15^\circ$  has an area of  $\frac{\pi}{3} \text{ cm}^2$ , find the radius of a circle.

#### Solution

$$\text{Given: } \theta = 15^\circ \frac{\pi}{180} = \frac{\pi}{12}; \quad A = \frac{\pi}{3}$$

$$A = \frac{1}{2} r^2 \theta$$

$$\frac{\pi}{3} = \frac{1}{2} r^2 \frac{\pi}{12}$$

$$\frac{24}{\pi} \frac{\pi}{3} = \frac{1}{2} r^2 \frac{\pi}{12} \frac{24}{\pi}$$

$$8 = r^2$$

$$\underline{r = 2\sqrt{2} \text{ cm}}$$

### Exercise

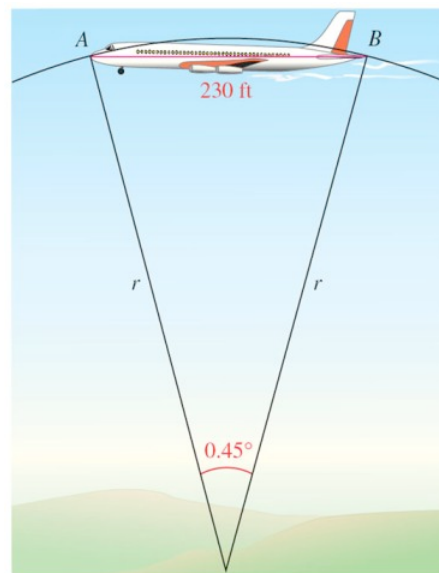
A person standing on the earth notices that a 747 jet flying overhead subtends an angle  $0.45^\circ$ . If the length of the jet is 230 ft., find its altitude to the nearest thousand feet.

#### Solution

$$r = \frac{230}{0.45 \left( \frac{\pi}{180} \right)} \quad r = \frac{s}{\theta}$$

$$\underline{= \frac{92,000}{\pi} \text{ ft}}$$

$$\underline{\approx 29,285 \text{ ft}}$$



### Exercise

Suppose that  $P$  is on a circle with radius 10 cm, and ray  $OP$  is rotating with angular speed  $\frac{\pi}{18} \text{ rad / sec}$ .

- Find the angle generated by  $P$  in 6 seconds
- Find the distance traveled by  $P$  along the circle in 6 seconds.
- Find the linear speed of  $P$  in cm per sec.

#### Solution

$$\text{a) } \theta = \frac{\pi}{18} \cdot 6 \quad \theta = \omega t$$

$$\underline{= \frac{\pi}{3} \text{ rad}}$$

$$b) \quad s = 10 \left( \frac{\pi}{3} \right) \quad s = r\theta$$

$$= \frac{10\pi}{3} \text{ cm}$$

$$c) \quad v = \frac{10\pi}{3} \frac{1}{6} \quad v = \frac{s}{t}$$

$$= \frac{5\pi}{9} \text{ cm / sec}$$

### Exercise

A belt runs a pulley of radius 6 cm at 80 rev / min.

- Find the angular speed of the pulley in radians per sec.
- Find the linear speed of the belt in cm per sec.

### Solution

$$a) \quad \omega = 80 \frac{\text{rev}}{\text{min}} \cdot \frac{1 \text{ min}}{60 \text{ sec}} \cdot \frac{2\pi}{1 \text{ rev}}$$

$$= \frac{8\pi}{3} \text{ rad / sec}$$

$$b) \quad v = 6 \left( \frac{8\pi}{3} \right) \quad v = r\omega$$

$$= 16\pi \text{ cm/sec} \quad \approx 50 \text{ cm / sec}$$

### Exercise

Find the linear velocity of a point moving with uniform circular motion, if  $s = 12 \text{ cm}$  and  $t = 2 \text{ sec}$ .

### Solution

$$v = \frac{12 \text{ cm}}{2 \text{ sec}} \quad v = \frac{s}{t}$$

$$= 6 \text{ cm / sec}$$

### Exercise

Find the distance  $s$  covered by a point moving with linear velocity  $v = 55 \text{ mi/hr}$  and  $t = 0.5 \text{ hr}$ .

### Solution

$$s = 55 \frac{\text{mi}}{\text{hr}} \times 0.5 \text{ hr} \quad s = vt$$

$$= 27.5 \text{ miles}$$

### Exercise

Point  $P$  sweeps out central angle  $\theta = 12\pi$  as it rotates on a circle of radius  $r$  with  $t = 5\pi$  sec. Find the angular velocity of point  $P$ .

#### Solution

$$\begin{aligned}\omega &= \frac{12\pi \text{ rad}}{5\pi \text{ sec}} & \omega &= \frac{\theta}{t} \\ &= \frac{12}{5} \\ &= \underline{2.4 \text{ rad / sec}}\end{aligned}$$

### Exercise

When Lance Armstrong blazed up Mount Ventoux in the 2002 tour, he was equipped with a 150-millimeter-diameter chainring and a 95-millimeter-diameter sprocket. Lance is known for maintaining a very high cadence, or pedal rate. If he was pedaling at a rate of 90 revolutions per minute, find his speed in kilometers per hour. (1 km = 1,000,000 mm or  $10^6$  mm)

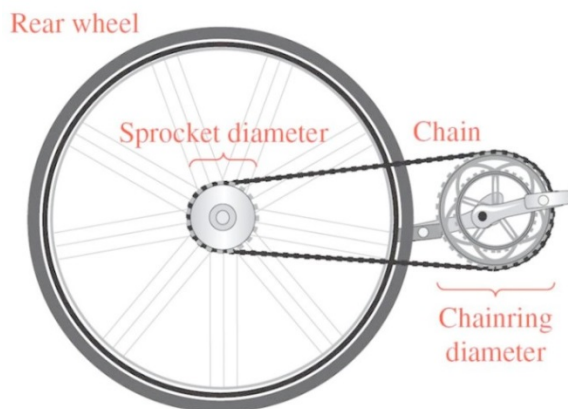
#### Solution

Chainring:

$$\begin{aligned}\omega &= \frac{v}{r} \\ &= 90 \frac{\text{rev}}{\text{min}} \times 2\pi \frac{\text{radians}}{\text{rev}} \times \frac{60 \text{ min}}{1 \text{ hr}} \\ &= \underline{10,800\pi \frac{\text{rad}}{\text{hr}}} \\ v &= r\omega \\ &= \frac{150}{2}(\text{mm}) \times 10800\pi \frac{\text{rad}}{\text{hr}} \\ &= \underline{810,000\pi \frac{\text{mm}}{\text{hr}}}\end{aligned}$$

Sprocket:

$$\begin{aligned}\omega &= \frac{v}{r} \\ &= \frac{810000\pi \frac{\text{mm}}{\text{hr}}}{\frac{95}{2}\text{mm}} \\ &= \underline{17,052.63\pi \frac{\text{rad}}{\text{hr}}} \\ v &= r\omega \\ &= 350(\text{mm}) \times \frac{1}{10^6} \frac{\text{km}}{\text{mm}} \times 17052.63\pi \frac{\text{rad}}{\text{hr}} \\ &= \underline{18.8 \frac{\text{km}}{\text{hr}}}\end{aligned}$$



### Exercise

Find the angular velocity, in radians per minute, associated with given 7.2 rpm.

### Solution

$$\begin{aligned}\omega &= 7.2 \frac{\text{rev}}{\text{min}} \times 2\pi \frac{\text{radians}}{\text{rev}} \\ &= \frac{144}{10} \pi \\ &= \frac{72\pi}{5} \text{ rad/min} \quad \approx 45.2 \frac{\text{rad}}{\text{min}}\end{aligned}$$

### Exercise

Suppose that point  $P$  is on a circle with radius 60 cm, and ray  $OP$  is rotating with angular speed  $\frac{\pi}{12}$  radian per sec.

- Find the angle generated by  $P$  in 8 sec.
- Find the distance traveled by  $P$  along the circle in 8 sec.
- Find the linear speed of  $P$ .

### Solution

$$\begin{aligned}a) \quad \theta &= \omega t = \frac{\pi}{12} \cdot 8 \\ &= \frac{2\pi}{3} \text{ rad}\end{aligned}$$

$$\begin{aligned}b) \quad s &= r\theta = 60 \left( \frac{2\pi}{3} \right) \\ &= 40\pi \text{ cm}\end{aligned}$$

$$c) \quad v = \frac{s}{t} = \frac{40\pi}{6} \text{ cm/sec}$$

### Exercise

Tires of a bicycle have radius 13 in. and are turning at the rate of 215 revolutions per min. How fast is the bicycle traveling in miles per hour? (Hint: 1 mi = 5280 ft.)

### Solution

$$\begin{aligned}\omega &= 215 \text{ rev} \frac{2\pi \text{ rad}}{1 \text{ rev}} \\ &= 430\pi \text{ rad/min} \\ v &= r\omega = 13(430\pi) \\ &= 5590\pi \text{ in/min}\end{aligned}$$



$$v = 5590\pi \frac{\text{in}}{\text{min}} \frac{60\text{min}}{1\text{hr}} \frac{1\text{ft}}{12\text{in}} \frac{1\text{mi}}{5280\text{ft}}$$

$$= \frac{2,795\pi}{528} \text{ mph} \quad \left| \quad \approx 16.6 \text{ mph} \right|$$

### Exercise

Earth travels about the sun in an orbit that is almost circular. Assume that the orbit is a circle with radius 93,000,000 *mi*. Its angular and linear speeds are used in designing solar-power facilities.

- Assume that a year is 365 *days*, and find the angle formed by Earth's movement in one day.
- Give the angular speed in *radians per hour*.
- Find the linear speed of Earth in *miles per hour*.

### Solution

$$a) \quad \theta = \frac{1}{365}(2\pi)$$

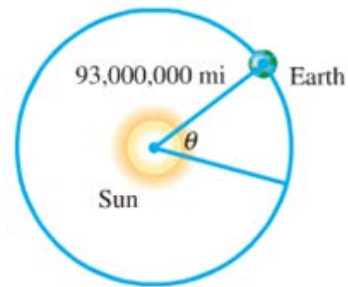
$$= \frac{2\pi}{365} \text{ rad} \quad \left| \right|$$

$$b) \quad \omega = \frac{2\pi \text{ rad}}{365 \text{ days}} \frac{1 \text{ day}}{24 \text{ hr}}$$

$$= \frac{\pi}{4380} \text{ rad / hr} \quad \left| \right|$$

$$c) \quad v = r\omega = (93,000,000) \frac{\pi}{4380}$$

$$\approx 67,000 \text{ mph} \quad \left| \right|$$



### Exercise

Earth revolves on its axis once every 24 *hr*. Assuming that earth's radius is 6400 *km*, find the following.

- Angular speed of Earth in radians per day and radians per hour.
- Linear speed at the North Pole or South Pole
- Linear speed at a city on the equator

### Solution

$$a) \quad \omega = \frac{2\pi \text{ rad}}{1 \text{ day}} \qquad \omega = \frac{\theta}{t}$$

$$= \frac{2\pi \text{ rad}}{1 \text{ day}} \frac{1 \text{ day}}{24 \text{ hr}}$$

$$= \frac{\pi}{12} \text{ rad / hr} \quad \left| \right|$$

$$b) \quad \text{At the poles, } r = 0 \text{ so } v = r\omega = 0$$

$$c) \quad \text{At the equator, } r = 6400 \text{ km}$$



$$\begin{aligned}
 v &= 6400(2\pi) & v &= rw \\
 &= 12,800\pi \text{ km} / \text{day} \\
 &= 12,800\pi \frac{\text{km}}{\text{day}} \frac{1 \text{ day}}{24 \text{ hr}} \\
 &\approx 533\pi \text{ km} / \text{hr}
 \end{aligned}$$

### Exercise

The pulley has a radius of 12.96 *cm*. Suppose it takes 18 *sec* for 56 *cm* of belt to go around the pulley.

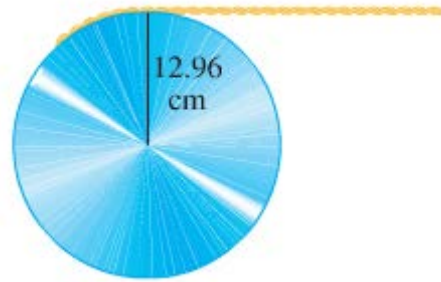
- Find the linear speed of the belt in *cm per sec*.
- Find the angular speed of the pulley in *rad per sec*.

### Solution

**Given:**  $s = 56 \text{ cm}$  in  $t = 18 \text{ sec}$   $r = 12.96 \text{ cm}$

$$\begin{aligned}
 a) \quad v &= \frac{s}{t} = \frac{56}{18} \\
 &\approx 3.1 \text{ cm} / \text{sec}
 \end{aligned}$$

$$\begin{aligned}
 b) \quad \omega &= \frac{v}{r} = \frac{3.1}{12.96} \\
 &= \frac{310}{1296} \\
 &= \frac{155}{648} \text{ rad} / \text{sec} \quad \approx .24 \text{ rad} / \text{sec}
 \end{aligned}$$



### Exercise

The two pulleys have radii of 15 *cm* and 8 *cm*, respectively. The larger pulley rotates 25 times in 36 *sec*. Find the angular speed of each pulley in *rad per sec*.

### Solution

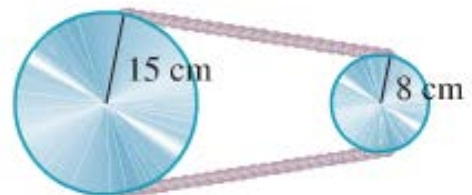
**Given:**  $\omega = \frac{25}{36} \text{ times} / \text{sec}$   $r_1 = 15 \text{ cm}$   $r_2 = 8 \text{ cm}$

The angular velocity of the larger pulley is:

$$\begin{aligned}
 \omega &= \frac{25 \text{ times}}{36 \text{ sec}} \frac{2\pi \text{ rad}}{1 \text{ time}} \\
 &= \frac{25\pi}{18} \text{ rad} / \text{sec}
 \end{aligned}$$

The linear velocity of the larger pulley is:

$$v = r\omega = 15 \left( \frac{25\pi}{18} \right)$$



$$= \frac{125\pi}{6} \text{ cm / sec}$$

The angular velocity of the smaller pulley is:

$$\begin{aligned}\omega &= \frac{v}{r} = \frac{1}{8} \cdot \frac{125\pi}{6} \\ &= \frac{125\pi}{48} \text{ rad / sec}\end{aligned}$$

### Exercise

A thread is being pulled off a spool at the rate of 59.4 *cm per sec*. Find the radius of the spool if it makes 152 *revolutions per min*.

### Solution

**Given:**  $\omega = 152 \text{ rev / min}$ ;  $v = 59.4 \text{ cm / sec}$

$$\begin{aligned}r &= \frac{1}{152 \frac{\text{rev}}{\text{min}}} 59.4 \frac{\text{cm}}{\text{sec}} & r = \frac{v}{\omega} = \frac{1}{\omega} v \\ &= \left( \frac{1}{152} \frac{\text{min}}{\text{rev}} \frac{60 \text{ sec}}{1 \text{ min}} \frac{1 \text{ rev}}{2\pi \text{ rad}} \right) \left( \frac{594 \text{ cm}}{10 \text{ sec}} \right) \\ &= \frac{891}{76\pi} \text{ cm} \\ &\approx 3.7 \text{ cm}\end{aligned}$$

### Exercise

A railroad track is laid along the arc of a circle of radius 1800 *feet*. The circular part of the track subtends a central angle of  $40^\circ$ . How long (in seconds) will it take a point on the front of a train traveling 30 *mph* to go around this portion of the track?

### Solution

**Given:**  $r = 1800 \text{ ft}$ .

$$\theta = 40^\circ = 40^\circ \frac{\pi}{180^\circ} = \frac{2\pi}{9} \text{ rad}$$

$$v = 30 \text{ mph}$$

The arc length:

$$\begin{aligned}s &= 1800 \left( \frac{2\pi}{9} \right) & s &= r\theta \\ &= 400\pi \text{ ft}\end{aligned}$$

$$v = \frac{s}{t} \Rightarrow t = \frac{s}{v}$$

$$\begin{aligned}
 t &= \frac{400\pi \text{ ft}}{30 \frac{\text{mi}}{\text{hr}}} \\
 &= \frac{40\pi}{3} \text{ ft} \frac{\text{hr}}{\text{mi}} \frac{1 \text{ mi}}{5280 \text{ ft}} \frac{3600 \text{ sec}}{1 \text{ hr}} \\
 &= \frac{1200\pi}{132} \text{ sec} \\
 &\approx 29 \text{ sec}
 \end{aligned}$$

### Exercise

A 90-horsepower outboard motor at full throttle will rotate its propeller at exactly 5,000 *revolutions per min.* Find the angular speed of the propeller in radians per second.

### Solution

$$\begin{aligned}
 \omega &= 5000 \frac{\text{rev}}{\text{min}} \frac{2\pi \text{ rad}}{1 \text{ rev}} \frac{1 \text{ min}}{60 \text{ sec}} \\
 &= \frac{500\pi}{3} \text{ rad / sec} \\
 &\approx 523.6 \text{ rad / sec}
 \end{aligned}$$

### Exercise

The shoulder joint can rotate at 25 *rad/min*. If a golfer's arm is straight and the distance from the shoulder to the club head is 5.00 *feet*., find the linear speed of the club head from the shoulder rotation.

### Solution

**Given:**  $\omega = 25 \text{ rad / min}$   $r = 5 \text{ ft}$

$$\begin{aligned}
 v &= r\omega = 5(25) \\
 &= 125 \text{ ft/min}
 \end{aligned}$$

### Exercise

A vendor sells two sizes of pizza by the slice. The small slice is  $\frac{1}{6}$  of a circular 18-inch-diameter pizza, and it sells for \$2.00. The large slice is  $\frac{1}{8}$  of a circular 26-inch-diameter pizza, and it sells for \$3.00. Which slice provides more pizza per dollar?

### Solution

Area of 18-inch-diameter:  $A = \pi r^2 = \pi \left(\frac{18}{2}\right)^2 = 81\pi$

Area of 26-inch-diameter:  $A = \pi r^2 = \pi \left(\frac{26}{2}\right)^2 = 169\pi$

For the small slice:  $\frac{1}{6} 81\pi \frac{1}{\$2} = 6.75\pi$

For the small slice:  $\frac{1}{8} 169\pi \frac{1}{\$3} \approx 7.04\pi$

$\therefore$  the Large size will provide more pizza per dollar

### Exercise

A cone-shaped tent is made from a circular piece of canvas 24 feet in diameter by removing a sector with central angle  $100^\circ$  and connecting the ends. What is the surface area of the tent?

#### Solution

$$\theta = 360^\circ - 100^\circ$$

$$= 260^\circ \frac{\pi}{180^\circ}$$

$$= \frac{13\pi}{9}$$

$$A_{\text{sector}} = \frac{1}{2} 12^2 \left(\frac{13\pi}{9}\right) \quad A_{\text{sector}} = \frac{1}{2} r^2 \theta$$

$$= 104\pi \text{ ft}^2 \quad \approx 326.73 \text{ ft}^2$$

### Exercise

A conical paper cup is constructed by removing a sector from a circle of radius 5 inches and attaching edge  $OA$  to  $OB$ . Find angle  $AOB$  so that the cap has a depth of 4 inches.

#### Solution

$$r^2 + 4^2 = 5^2 \rightarrow r = 3 \text{ in}$$

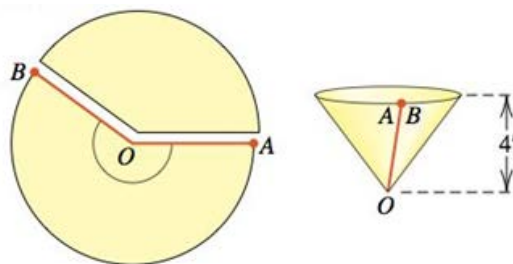
The circumference of the rim of the cone is:

$$2\pi r = 6\pi$$

$$\theta = \frac{s}{r} = \frac{6\pi}{5} \text{ rad}$$

$$= \frac{6(180)}{5}$$

$$= 216^\circ$$



### Exercise

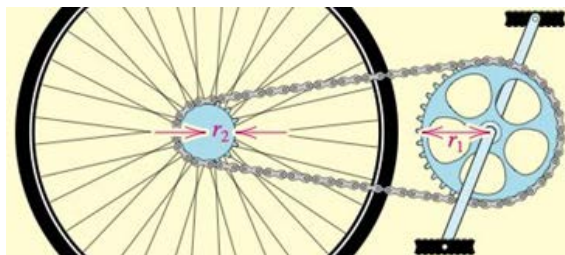
The sprocket assembly for a bicycle is shown in the figure. If the sprocket of radius  $r_1$  rotates through an angle of  $\theta_1$  radians, find the corresponding angle of rotation for the sprocket of radius  $r_2$ .

### Solution

$$s_1 = s_2$$

$$r_1 \theta_1 = r_2 \theta_2$$

$$\theta_2 = \frac{r_1 \theta_1}{r_2}$$



### Exercise

A simple model of the core of a tornado is a right circular cylinder that rotates about its axis. If a tornado has a core diameter of 200 feet and maximum wind speed of 180 mi/hr. (or 264 ft/sec) at the perimeter of the core, approximate the number of revolutions the core makes each minute.

### Solution

$$r = \frac{D}{2} = \frac{200}{2}$$
$$= 100 \text{ ft}$$

$$264 = 100\theta$$

$$v = r\omega$$

$$\theta = 2.64 \frac{\text{rad}}{\text{sec}} \frac{60 \text{ sec}}{1 \text{ min}} \frac{1 \text{ rev}}{2\pi \text{ rad}}$$
$$\approx 25.2 \text{ rev / min}$$

### Exercise

Earth rotates about its axis once every 23 hours, 56 minutes, and 4 seconds. Approximate the number of radians Earth rotates in one second.

### Solution

$$23 \text{ hr} \frac{3600 \text{ sec}}{1 \text{ h}} + 56 \text{ min} \frac{60 \text{ sec}}{1 \text{ min}} + 4 \text{ sec} = 85,984 \text{ sec}$$

Earth rotates in one second:

$$\frac{1 \text{ rev}}{85,984 \text{ sec}} = 2\pi \text{ rad} \left( \frac{1}{85,984 \text{ sec}} \right)$$
$$\approx 7.31 \times 10^{-5} \text{ rad / sec}$$

### Exercise

A typical tire for a compact car is 22 inches in diameter. If the car is traveling at a speed of 60 mi/hr., find the number of revolutions the tire makes per minute.

#### Solution

$$r = \frac{D}{2} = \frac{22}{2} \\ = 11 \text{ in}$$

$$60 = 11\theta$$

$$v = r\omega$$

$$\theta = \frac{1}{11 \text{ in}} 60 \frac{\text{mi}}{\text{hr}} \frac{12 \text{ in}}{1 \text{ ft}} \frac{5280 \text{ ft}}{1 \text{ mil}} \frac{1 \text{ hr}}{60 \text{ min}} \frac{1 \text{ rev}}{2\pi \text{ rad}} \\ \approx 916.73 \text{ rev / min}$$

### Exercise

A pendulum in a grandfather clock is 4 feet long and swings back and forth along a 6-inch arc. Approximate the angle (in degrees) through which the pendulum passes during one swing.

#### Solution

**Given:**  $r = 4 \text{ ft} = 48 \text{ in}$     $s = 6 \text{ in}$

$$\theta = \frac{s}{r} = 0.125 \text{ rad} \\ = 0.125 \text{ rad} \frac{180^\circ}{\pi \text{ rad}} \\ = 7.162^\circ$$

### Exercise

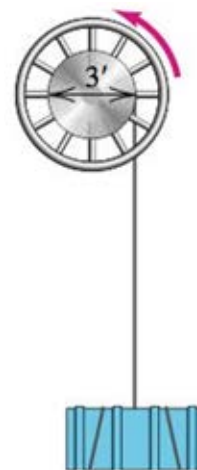
A large winch of diameter 3 feet is used to hoist cargo.

- Find the distance the cargo is lifted if the winch rotates through an angle measure  $\frac{7\pi}{4}$ .
- Find the angle (in radians) through which the winch must rotate in order to lift the cargo  $d$  feet.

#### Solution

$$a) \quad s = \frac{3}{2} \frac{7\pi}{4} \\ = \frac{21\pi}{8} \text{ ft} \approx 8.25 \text{ ft}$$

$$s = r\theta$$



$$b) \quad \theta = \frac{d}{\frac{3}{2}}$$

$$\quad \quad \quad \underline{= \frac{2}{3}d}$$

$$\theta = \frac{s}{r}$$