

## Angles and Arc-Length

In this set of notes, we'll study some conventions and terminology that we will use when discussing angles within circles, like angle  $\theta$  in Figure 1.

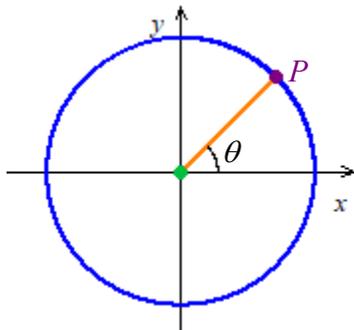


Figure 1

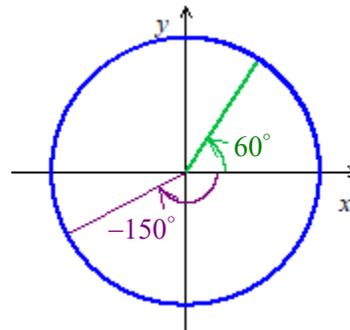


Figure 2

- The angle  $\theta$  is measured **counterclockwise from the positive  $x$ -axis**. Consequently, negative angles are measured *clockwise* from the positive  $x$ -axis; see Figure 2.
- The segment between the origin,  $(0, 0)$ , and the point  $P$  is the **terminal side of angle  $\theta$** .
- The point  $P$  on the circumference of the circle is said to be **specified by the angle  $\theta$** .
- Angle  $\theta$  corresponds with a portion of the circumference of the circle called the **arc spanned by  $\theta$** . (We'll discuss finding the **length** of this arc.)
- Two angles with the same terminal side are said to be **co-terminal angles**.

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Thus far in your mathematics careers you've probably measured angles in **degrees**:  $360^\circ$  represents a complete trip around a circle (i.e., a full rotation), so  $1^\circ$  corresponds to  $1/360^{\text{th}}$  of a full rotation; see Fig. 3.

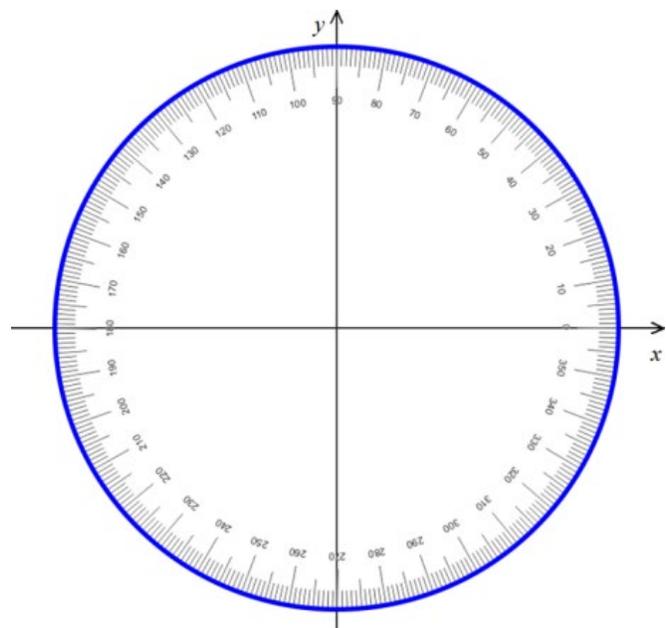


Figure 3

We mentioned above that *co-terminal angles* share the same terminal side. Since  $360^\circ$  represents a full rotation about the circle, if we add any integer multiple of  $360^\circ$  to an angle  $\theta_1$ , we'll obtain an angle co-terminal to  $\theta_1$ . In other words, the angles

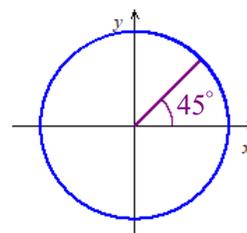
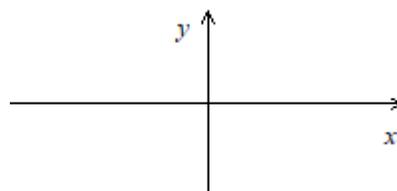


Figure 4

are co-terminal. So  $45^\circ$  and \_\_\_\_\_ are co-terminal.

Traditionally, the coordinate plane is divided into **four quadrants**. We will often use the names of these quadrants to describe the location of the terminal side of different angles.



**DEFINITION:** The **radian** measure of an angle is the ratio of the length of the arc on the circumference of the circle spanned by the angle,  $s$ , and the radius,  $r$ , of the circle; see Figure 5.

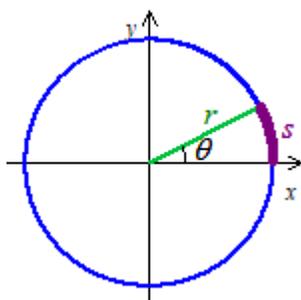
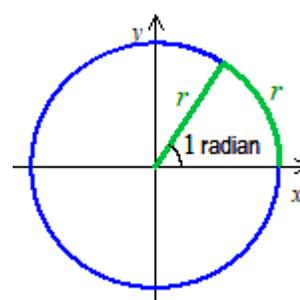
Figure 5:  $\theta$  measures  $\frac{s}{r}$  radian.

Figure 6: 1 radian.

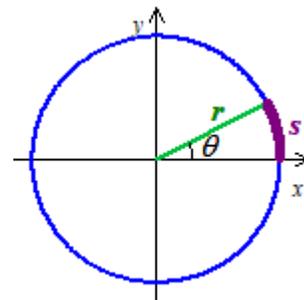
An alternative yet equivalent definition is that an angle that measures 1 **radian** spans an arc whose length is equal to the length of the radius,  $r$ ; see Figure 6.

Since a radian is a ratio of two lengths, the length-units cancel; thus, radians are considered a **unit-less measure**.

(For more on radians, see this video that's linked from the online lecture notes: <https://youtu.be/93cTjSTS4Gs>.)



Recall that the *radian measure* of an angle is the ratio of the length of the arc on the circumference of the circle spanned by the angle and the radius of the circle. Applying this fact to the circle in Figure 7 if  $\theta$  is measured in radians, then...



**Figure 7:** Circle of radius  $r$  with an angle  $\theta$  spanning an arc of length  $s$ .

**DEFINITION:** The **arc length**  $s$  spanned in a circle of radius  $r$  by an angle  $\theta$  measured in radians is given by:

*Note that this formula only applies if  $\theta$  is measured in radians!*

**EXAMPLE:** What is the arc length spanned by a  $40^\circ$  angle on a circle of radius 30 meters?

# Intro to the Trigonometric Functions: Part 1

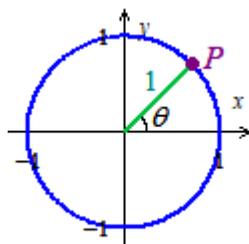
(these notes correspond to Parts 1 & 2 from my MTH 112 Online Lecture Notes)

As we noticed in the Ferris wheel example, a circle rotating about its center lends itself naturally to the study of periodic functions. In fact, the two most important *trigonometric functions* are defined in terms of a unit circle: the **sine** and **cosine** functions. (Note that a **unit circle** is a circle with a radius of 1 unit; see Figure 1.)

**DEFINITIONS:**

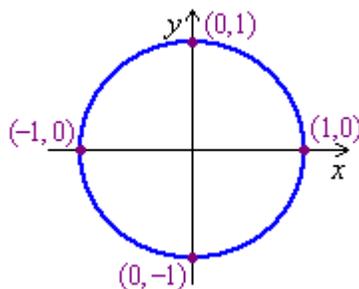
The **sine function**, denoted  $\sin(\theta)$ , associates each angle  $\theta$  with the vertical coordinate (i.e., the  $y$ -coordinate) of the point  $P$  specified by the angle  $\theta$  on the circumference of a unit circle.

The **cosine function**, denoted  $\cos(\theta)$ , associates each angle  $\theta$  with the horizontal coordinate (i.e., the  $x$ -coordinate) of the point  $P$  specified by the angle  $\theta$  on the circumference of a unit circle.



**Figure 1:** A Unit Circle

There are four other trigonometric functions. These four functions are defined in terms of the sine and cosine functions so first let's get familiar with sine and cosine. In order to enhance our understanding of the sine and cosine functions, we should determine some particular values for the functions and sketch their graphs. The easiest values for us to find are represented by the points where the unit circle intersects the coordinate axes. Use the graph in Figure 2 to complete Table 1. (Keep in mind that cosine represents the horizontal coordinate and sine represents the vertical coordinate.)

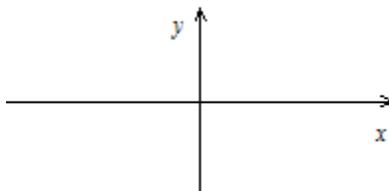


**Figure 2**

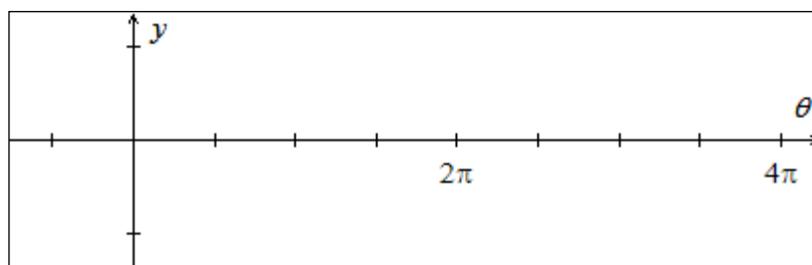
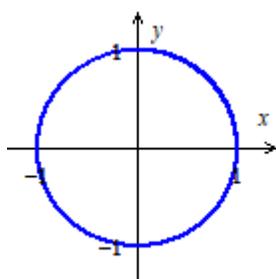
$\theta$ (degrees)	$0^\circ$	$90^\circ$	$180^\circ$	$270^\circ$	$360^\circ$	$450^\circ$	$540^\circ$
$\theta$ (radians)							
$\cos(\theta)$							
$\sin(\theta)$							

**Table 1**

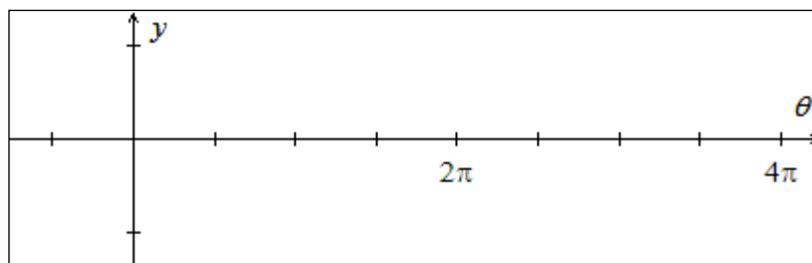
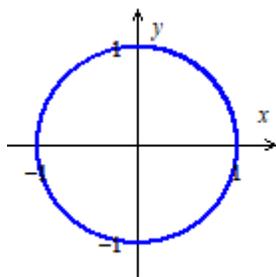
Let's determine the signs (positive or negative) of the sine and cosine functions in the four different quadrants of the coordinate plane. Notice that our analysis of the signs of the sine and cosine functions agree with the graphs of the sine and cosine functions.



Now, let's plot on coordinate planes the info from Table 1 and sketch graphs of the sine and cosine functions. Be sure to add **scale** to the  $y$ -axis and label *all* of the "tics" on the  $\theta$ -axis.



The graph of  $y = \sin(\theta)$ .



The graph of  $y = \cos(\theta)$ .

Notice that angles of measure  $2\pi$  radians (i.e.,  $\theta = 360^\circ$ ) and 0 radians specify the same point on the unit circle:  $(1, 0)$ . Thus, the sine and cosine values for  $2\pi$  radians and 0 radians are the same. In general,  $\theta$  and  $\theta + 2\pi$  specify the *same* point on the unit circle, so the sine and cosine values of  $\theta$  and  $\theta + 2\pi$  are the same. Thus, **the period of the sine and cosine functions is  $2\pi$  radians**.

For all  $\theta$ ,  $\sin(\theta) = \sin(\theta + 2\pi)$  and  $\cos(\theta) = \cos(\theta + 2\pi)$ .

[Let's use Desmos to confirm that we have correct graphs and to discuss what happens when we graph these functions with  $\theta$  in degrees instead of radians.]

Notice that the graphs of  $y = \sin(\theta)$  and  $y = \cos(\theta)$  are very similar. In fact, if we shift the graph of  $y = \sin(\theta)$  ....

This equation is known as an **identity** since the left and right sides of the equation are *always* identical, no matter what value of  $\theta$  is used.

**DEFINITION:** An **identity** is an equation that is true for all values in the domains of the involved expressions.

Earlier in these notes we observed a couple of identities but didn't call them identities. The equations

$$\sin(\theta) = \sin(\theta + 2\pi) \quad \text{and} \quad \cos(\theta) = \cos(\theta + 2\pi)$$

are identities since they are true for *all* values of  $\theta$ . We can use the definitions and graphs of sine and cosine to determine a few other important identities. (You should spend some time using what you learned in MTH 111 about graph transformations and symmetry to make sense of WHY these identities are true.)

### SOME IMPORTANT TRIG IDENTITIES

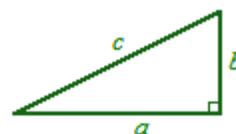
- $\cos(\theta) = \cos(\theta + 2\pi)$
- $\sin(\theta) = \sin(\theta + 2\pi)$
- $\cos(\theta) = \sin\left(\theta + \frac{\pi}{2}\right)$
- $\sin(\theta) = \cos\left(\theta - \frac{\pi}{2}\right)$
- $\cos(-\theta) = \cos(\theta)$
- $\sin(-\theta) = -\sin(\theta)$
- $\cos(\theta) = \cos(2\pi - \theta)$
- $\sin(\theta) = \sin(\pi - \theta)$

We'll study more identities in these lecture notes, and even more over the next few weeks.

Recall the Pythagorean Theorem from your previous math course-work:

### THE PYTHAGOREAN THEOREM:

If the sides of a right triangle (i.e., a triangle with a  $90^\circ$  angle) are labeled like the one given in Figure 3, then  $a^2 + b^2 = c^2$ .



**Figure 3**

We can use the Pythagorean Theorem along with the definitions of sine and cosine to derive another important identity. In Figure 4, notice how the definitions of sine and cosine naturally lead us to a right triangle with side-lengths  $\sin(\theta)$ ,  $\cos(\theta)$ , and 1.

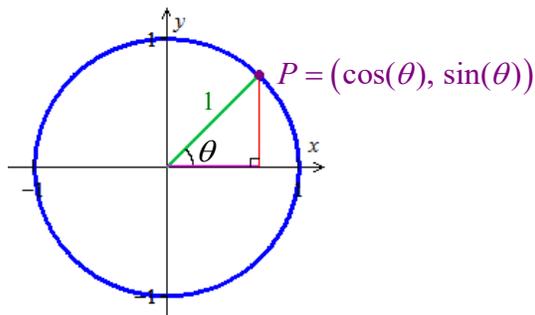


Figure 4

### The Pythagorean Identity:

We can generalize the definitions of the sine and cosine functions so that they are applicable to circles of any size, rather than only for unit circles.



**DEFINITION:** If the point  $T = (x, y)$  is specified by the angle  $\theta$  on the circumference of a circle of radius  $r$  as shown in Figure 5 below, then

Notice that if  $r = 1$  then this definition  $\cos(\theta)$  and  $\sin(\theta)$  is equivalent we saw at the beginning of this chapter:

If we solve the equations  $\cos(\theta) = \frac{x}{r}$  and  $\sin(\theta) = \frac{y}{r}$  for  $x$  and  $y$ , respectively, we can obtain the coordinates of a point on the circumference of a circle of any  $r$ :

If the point  $T = (x, y)$  is specified by the angle  $\theta$  on the circumference of a circle of radius,  $r$ , then

Let's add this information to Figure 5.

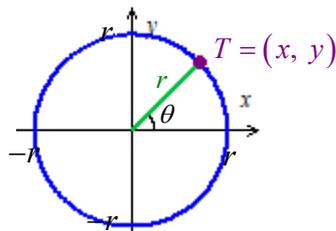


Figure 5

As mentioned at the beginning of these notes, there are four other trigonometric functions. These four functions are defined in terms of the sine and cosine functions:

**DEFINITIONS:** The **tangent function**, denoted  $\tan(\theta)$  is defined by\_\_\_\_\_.

The **cotangent function**, denoted  $\cot(\theta)$ , is defined by\_\_\_\_\_.

Consequently:

The **secant function**, denoted  $\sec(\theta)$  is defined by\_\_\_\_\_.

The **cosecant function**, denoted  $\csc(\theta)$  is defined by\_\_\_\_\_.

We can use the Pythagorean Identity to derive two identities that involve these so-called “other trig functions”:

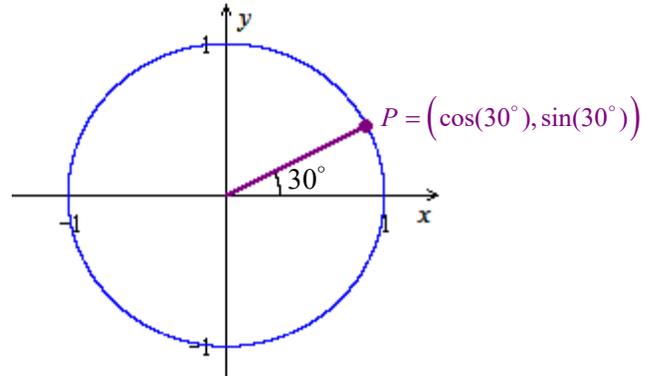
### The Pythagorean Identities

**EXAMPLE:** If  $\cos(A) = -\frac{5}{7}$  and  $\pi < A < \frac{3\pi}{2}$ , find  $\sin(A)$ ,  $\tan(A)$ ,  $\cot(A)$ ,  $\sec(A)$ , and  $\csc(A)$ .

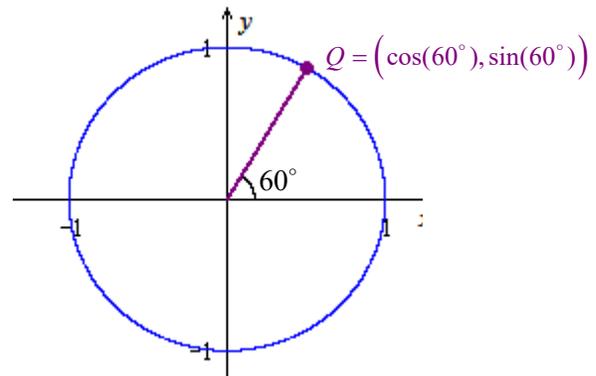
## Intro to the Trigonometric Functions: Part 2

(these notes correspond to Parts 3 & 4 from my MTH 112 Online Lecture Notes)

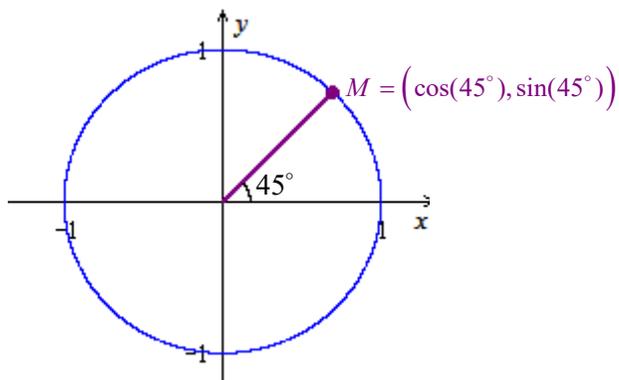
Now let's determine the sine and cosine of some important angles, namely,  $30^\circ$ ,  $45^\circ$ , and  $60^\circ$  (i.e.,  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$ , and  $\frac{\pi}{3}$ ). Let's start with  $30^\circ = \frac{\pi}{6}$ .



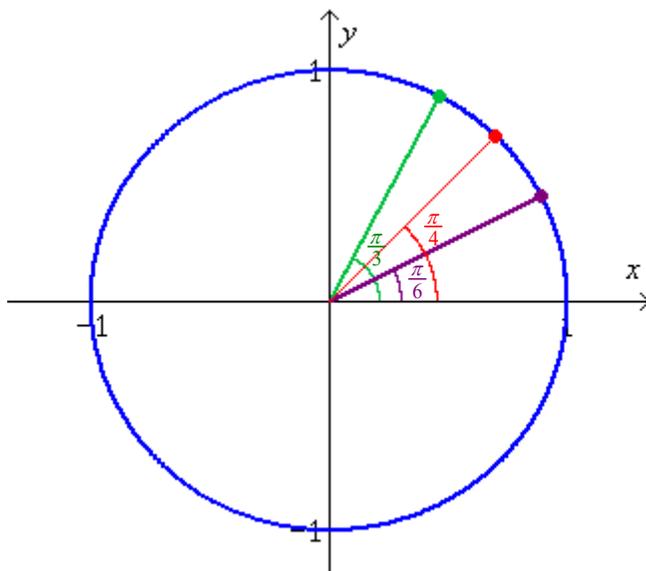
Now let's find the sine and cosine values for  $60^\circ = \frac{\pi}{3}$ .



Now let's find the sine and cosine values for  $45^\circ = \frac{\pi}{4}$ :



Since we now know the sine and cosine values of  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$ , and  $\frac{\pi}{3}$ , and since sine and cosine represent, respectively, the vertical and horizontal coordinates of points on the circumference of a unit circle, we now know the coordinates of the points on the circumference of the unit circle specified by the angles  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$ , and  $\frac{\pi}{3}$ ; let's label the coordinates on the circle in Fig. 1.



**Figure 1**

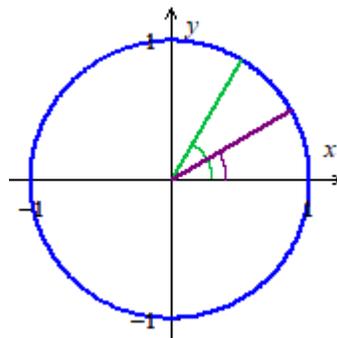
Now let's watch the [video](#) in Sect. I, Chapter 3, part 4 of the online lecture notes. (18 minutes)

## Finding the sine and cosine of “friendly” angles:

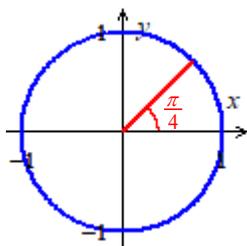
Let's summarize what we've observed about the sine and cosine of multiples of  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$  or  $\frac{\pi}{3}$ :

Multiples of  $\frac{\pi}{4}$ :

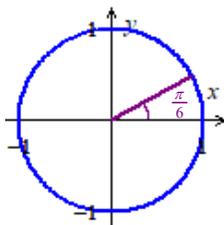
Multiples of  $\frac{\pi}{6}$  and  $\frac{\pi}{3}$ :



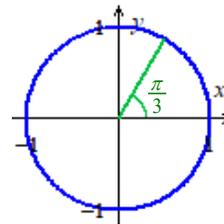
**EXAMPLE:** Find  $\sin\left(\frac{21\pi}{4}\right)$ ,  $\cos\left(\frac{21\pi}{4}\right)$ , and  $\tan\left(\frac{21\pi}{4}\right)$ .



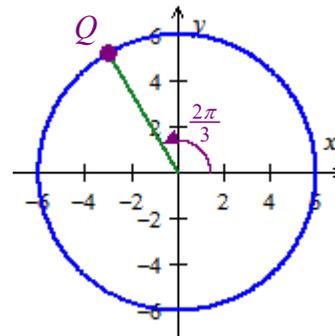
**EXAMPLE:** Find  $\sin\left(\frac{17\pi}{6}\right)$ ,  $\cos\left(\frac{17\pi}{6}\right)$ , and  $\sec\left(\frac{17\pi}{6}\right)$ .



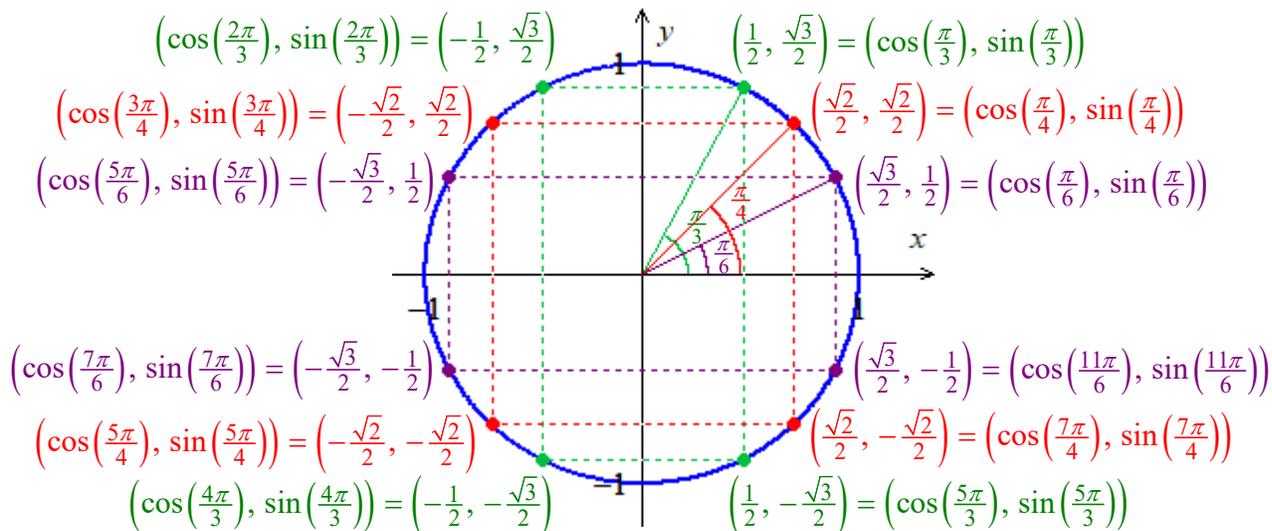
**EXAMPLE:** Find  $\sin\left(\frac{14\pi}{3}\right)$ ,  $\cos\left(\frac{14\pi}{3}\right)$ , and  $\csc\left(\frac{14\pi}{3}\right)$ .



**EXAMPLE:** A circle with a radius of 6 units is given below. The point  $Q$  is specified by the angle  $\frac{2\pi}{3}$ . Use the sine and cosine function to find the exact coordinates of point  $Q$ .



**Last slide from video: “Working with Multiples of  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$ , and  $\frac{\pi}{3}$ ”**



## Graphing Sinusoidal Functions

Below is a summary of what is studied in MTH 111 about graph transformations; see Section I, Units 6–8 from my [online notes for MTH 111](#) to review graph transformations.

### SUMMARY OF GRAPH TRANSFORMATIONS

Suppose that  $f$  and  $g$  are functions such that  $g(t) = A \cdot f(\omega(t - h)) + k$  and  $A, \omega, h, k \in \mathbb{R}$ . In order to transform the graph of the function  $f$  into the graph of  $g$ :

- 1<sup>st</sup>:** horizontally stretch/compress the graph of  $f$  by a factor of  $\frac{1}{|\omega|}$  and, if  $\omega < 0$ , reflect it about the  $y$ -axis. (Stretch if  $|\omega| < 1$ ; compress if  $|\omega| > 1$ .)
- 2<sup>nd</sup>:** shift the graph horizontally  $h$  units (shift right if  $h > 0$ ; shift left if  $h < 0$ ).
- 3<sup>rd</sup>:** vertically stretch/compress the graph by a factor of  $|A|$  and, if  $A < 0$ , reflect it about the  $t$ -axis. (Stretch if  $|A| > 1$ ; compress if  $|A| < 1$ .)
- 4<sup>th</sup>:** shift the graph vertically  $k$  units (shift up if  $k$  is positive and down if  $k$  is negative).

**(The order in which these transformations are performed matters.)**

When we apply these graph transformations to the graphs of  $y = \sin(t)$  and  $y = \cos(t)$  we obtain *sinusoidal functions*:

**DEFINITION:** A **sinusoidal function** is function  $f$  of the form

$$f(t) = A \sin(\omega(t - h)) + k \quad \text{or} \quad f(t) = A \cos(\omega(t - h)) + k$$

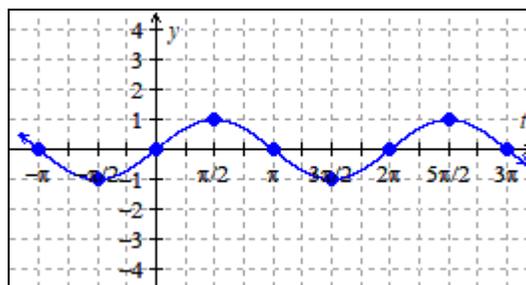
where  $A, \omega, h, k \in \mathbb{R}$ ,  $A \neq 0$ , and  $\omega \neq 0$ .

A sinusoidal function of this form has the following properties:

- |   |   |
|---|---|
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(We'll use the examples below to determine the properties for the box above.)

**EXAMPLE:** The graph of  $f(t) = \sin(t)$  is given below. Sketch a graph of  $y = 3\sin(t)$ .

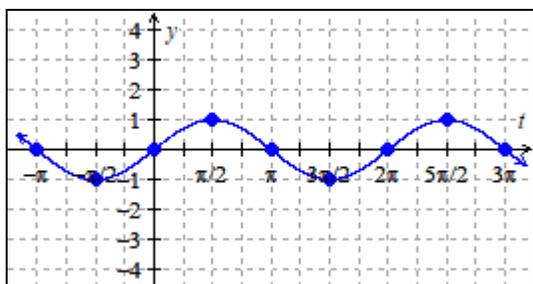


Sketch a graph of  $y = 3\sin(t)$ .

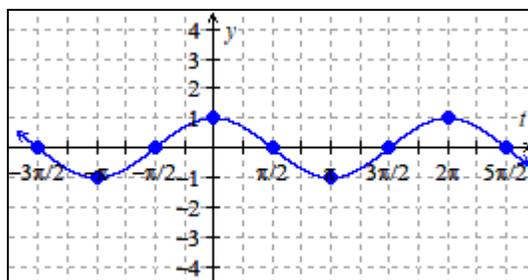
Use [Desmos](#) to graph  $f(t) = \sin(t)$  &  $y = A\sin(t)$  and  $g(t) = \cos(t)$  &  $y = A\cos(t)$  for various values of  $A > 0$ ; then complete the following sentence:

- The graphs of  $y = A\sin(t)$  and  $y = A\cos(t)$  have \_\_\_\_\_.

**EXAMPLE:** The graph of  $f(t) = \sin(t)$  is given below; sketch a graph of  $y = -2\sin(t)$ ; also the graph of  $g(t) = \cos(t)$  is given below; sketch a graph of  $y = -4\cos(t)$ .



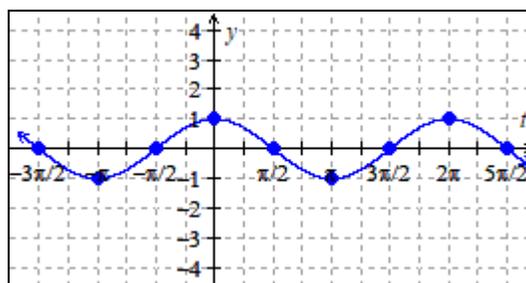
Sketch a graph of  $y = -2\sin(t)$ .



Sketch a graph of  $y = -4\cos(t)$ .

Observation: The reflected sine wave “starts” \_\_\_\_\_ while the reflected cosine wave “starts” \_\_\_\_\_.

**EXAMPLE:** The graph of  $g(t) = \cos(t)$  is given below. Sketch a graph of  $y = \cos(t) + 2$ .

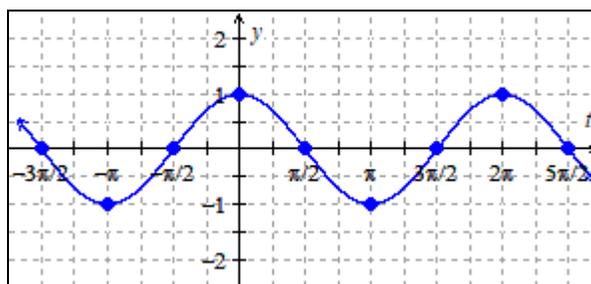


Sketch a graph of  $y = \cos(t) + 2$ .

Use [Desmos](#) to graph  $g(t) = \cos(t)$  &  $y = \cos(t) + k$  and  $f(t) = \sin(t)$  &  $y = \sin(t) + k$  for various values of  $k$ ; then complete the following sentence:

- The graphs of  $y = \cos(t) + k$  and  $y = \sin(t) + k$  have \_\_\_\_\_.

**EXAMPLE:** The graph of  $g(t) = \cos(t)$  is given below. Sketch a graph of  $y = \cos(2t)$ .

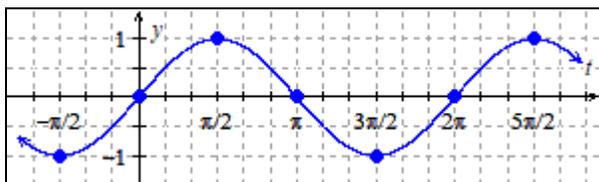


Sketch a graph of  $y = \cos(2t)$ .

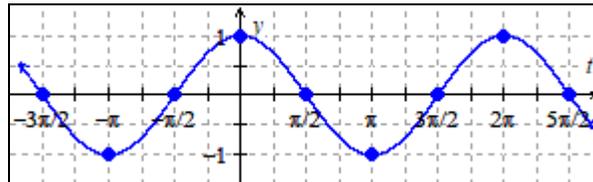
Use [Desmos](#) to graph  $g(t) = \cos(t)$  &  $y = \cos(\omega \cdot t)$  and  $f(t) = \sin(t)$  &  $y = \sin(\omega \cdot t)$  for various values of  $\omega > 0$ ; then complete the following sentence:

- The graphs of  $y = \cos(\omega \cdot t)$  and  $y = \sin(\omega \cdot t)$  ...

**EXAMPLE:** The graphs of  $f(t) = \sin(t)$  and  $g(t) = \cos(t)$  are given below; sketch graphs of  $y = \sin\left(t - \frac{\pi}{3}\right)$  and  $y = \cos\left(t + \frac{\pi}{4}\right)$ .



Sketch a graph of  $y = \sin\left(t - \frac{\pi}{3}\right)$ .

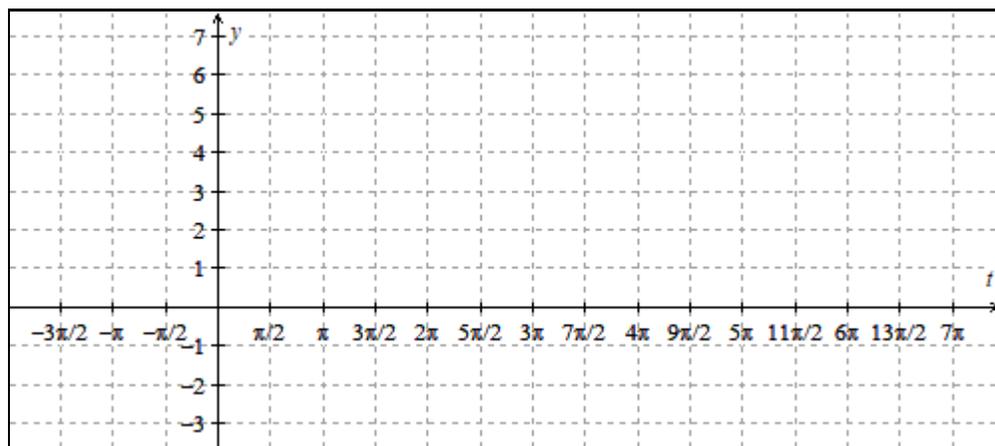


Sketch a graph of  $y = \cos\left(t + \frac{\pi}{4}\right)$ .

**EXAMPLE:** Use [Desmos](#) to compare  $p(t) = \cos\left(2t - \frac{\pi}{3}\right)$  and  $q(t) = \cos\left(2\left(t - \frac{\pi}{3}\right)\right)$ . Determine the appropriate horizontal shift for each function.

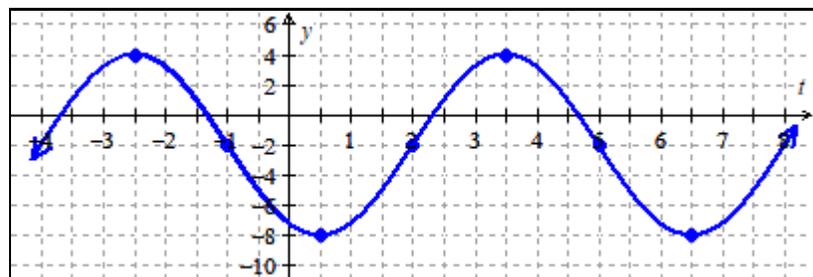
Observation: To determine the horizontal shift, first factor the input of the trig function.

**EXAMPLE:** Sketch a graph of  $m(t) = 2 \sin\left(\frac{1}{2}t + \frac{\pi}{4}\right) + 3$ . State the period, midline, and amplitude of  $m$ .



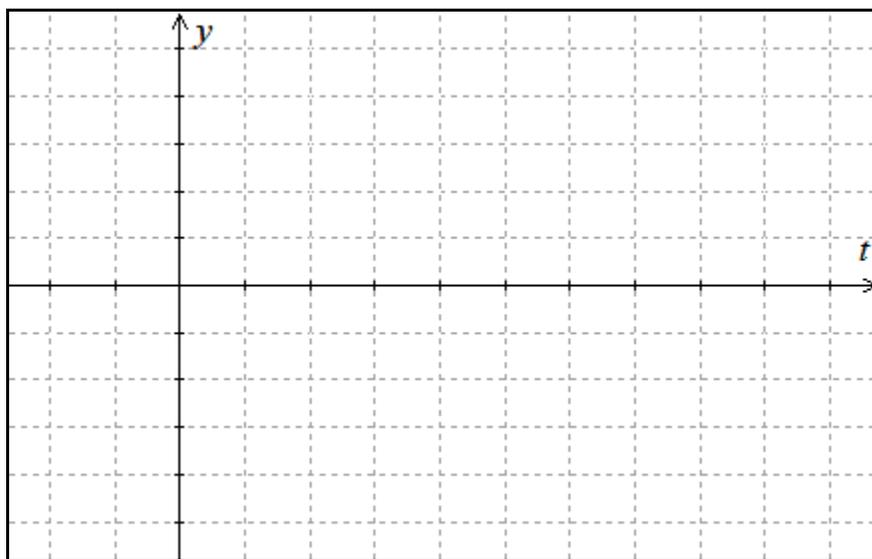
Sketch a graph of  $m(t) = 2 \sin\left(\frac{1}{2}t + \frac{\pi}{4}\right) + 3$ .

**EXAMPLE:** Find (at least) two algebraic rules (i.e., “formulas”), one involving sine and one involving cosine, for the sinusoidal function  $n$  whose graph is given below.



The graph of  $y = n(t)$ .

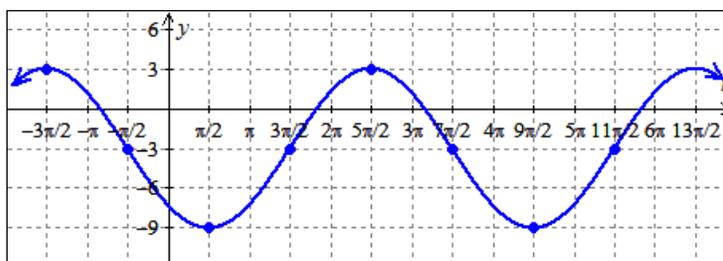
**EXAMPLE:** Sketch a graph of  $f(t) = 2 \sin\left(\pi t - \frac{\pi}{4}\right) - 3$  on the coordinate plane below.



Sketch a graph of  $f(t) = 2 \sin\left(\pi t - \frac{\pi}{4}\right) - 3$ .

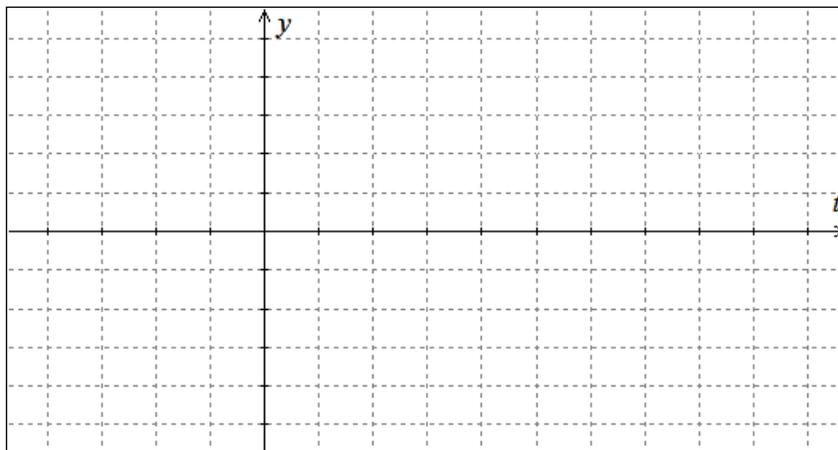
**Additional Examples:**

- a. Find (at least) two algebraic rules (i.e., “formulas”), one involving sine and one involving cosine, for the sinusoidal function  $f$  whose graph is given below.



The graph of  $y = f(t)$ .

- b. Sketch a graph of  $g(t) = 3\cos\left(\frac{\pi}{2}t - \frac{\pi}{4}\right) - 1$  on the coordinate plane below.  
List the *period*, *amplitude*, *midline*, and *horizontal shift*.



Sketch a graph of  $g(t) = 3\cos\left(\frac{\pi}{2}t - \frac{\pi}{4}\right) - 1$ .

## Graphs of the Other Trigonometric Functions

Recall the definitions of the “other trig functions”:

**DEFINITIONS:** The **tangent function** is defined by \_\_\_\_\_.

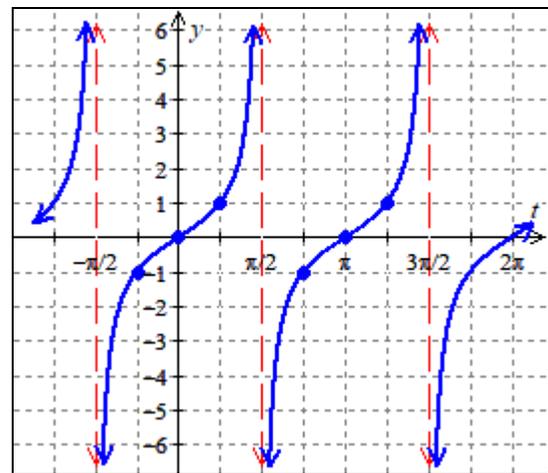
The **cotangent function** is defined by \_\_\_\_\_.

Consequently:

The **secant function** is defined by \_\_\_\_\_.

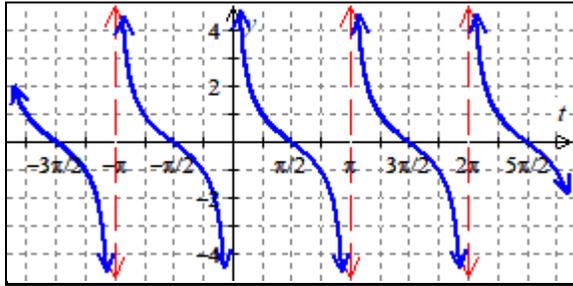
The **cosecant function** is defined by \_\_\_\_\_.

Below is the graph  $y = \tan(t)$ . Let's discuss why the graph looks like it does.



A graph  $y = \tan(t)$ .

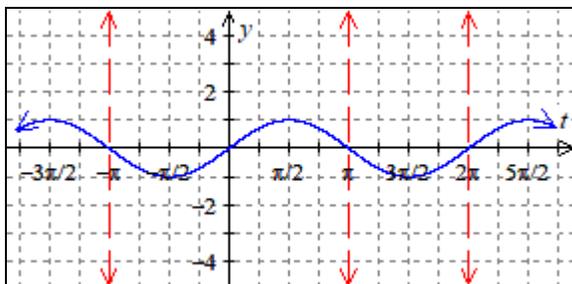
Below is the graph of  $y = \cot(t)$ . Let's discuss why it looks like it does.



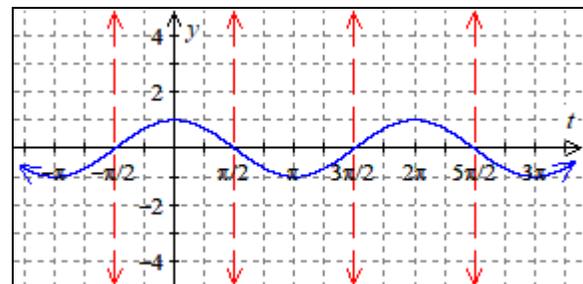
A graph of  $y = \cot(t)$ .

---

Let's sketch graphs of  $y = \sec(t)$  and  $y = \csc(t)$ .



Draw a graph of \_\_\_\_\_.



Draw graph of \_\_\_\_\_.

# Inverse Trig Functions

As we studied in MTH 111, the inverse of a function reverses the roles of the inputs and the outputs. (For more info on inverse functions, check out my [MTH 111 Online Lecture Notes](#).)

Suppose that  $f$  and  $f^{-1}$  are inverses. If  $f(a) = b$ , then \_\_\_\_\_.

Inverse functions are extremely valuable since they “undo” one another and allow us to solve equations. For example, we can solve the equation  $x^3 = 10$  by using the inverse of the cubing function, the cube-root function, to “undo” the cubing involved in the equation:

The cubing function has an inverse function because it’s **one-to-one**, which means that each output value corresponds to exactly one input value (e.g., the only number with a cube of 8 is 2) – this will allow us to reverse the roles of the inputs and outputs and still have a function. Let’s use the graphs below of  $y = x^2$  and  $y = x^3$  to review one-to-one functions vs. not one-to-one functions.

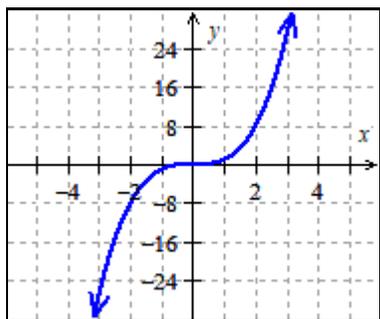


Figure 1:  $y = x^3$

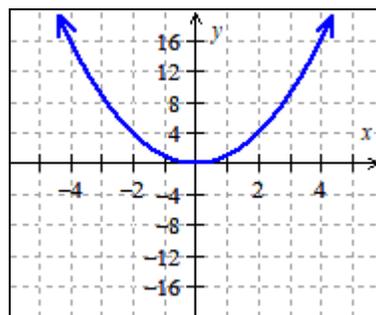


Figure 2:  $y = x^2$

Unfortunately, the trig functions aren’t one-to-one so, in their natural form, they don’t have inverse functions. For example, consider the output  $\frac{1}{2}$  for the cosine function: this output corresponds to the inputs  $-\frac{\pi}{3}$ ,  $\frac{\pi}{3}$ ,  $\frac{5\pi}{3}$ ,  $\frac{7\pi}{3}$ , etc.; see Figure 3.

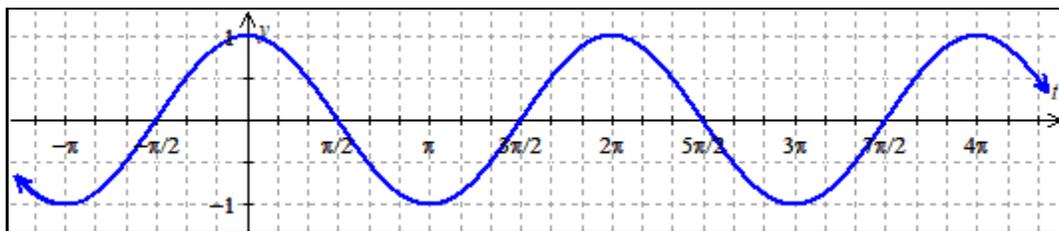
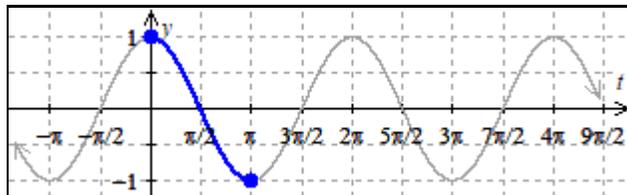


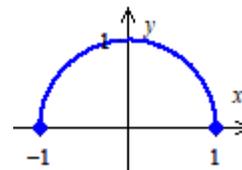
Figure 3: The graph of  $y = \cos(t)$ .

Since inverse functions are so valuable, we *really* want inverse trig functions, so we need to **restrict the domains** of the functions to intervals on which they are one-to-one, and then we can construct inverse functions.

Let's start by constructing the inverse of the cosine function.



A graph of  $y = \cos(t)$ .



**DEFINITION:** The **inverse cosine function**,  $y = \cos^{-1}(t)$ , is defined by:

If  $0 \leq y \leq \pi$  and  $\cos(y) = t$ , then  $y = \cos^{-1}(t)$ .

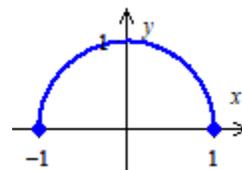
The *domain* of  $y = \cos^{-1}(t)$  is \_\_\_\_\_ (which is the range of the cosine function) and the *range* of  $y = \cos^{-1}(t)$  is \_\_\_\_\_.

This function is often called **arccosine** and is expressed as  $y = \arccos(t)$ .

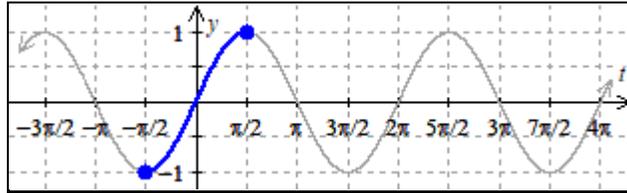


**Key Point:** Inverse Notation vs. Exponent Notation:

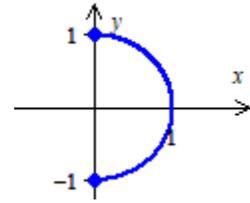
**EXAMPLE:** Evaluate  $\cos^{-1}\left(\frac{1}{2}\right)$ .



Now we'll construct the inverse of the sine function.



A graph of  $y = \sin(t)$ .



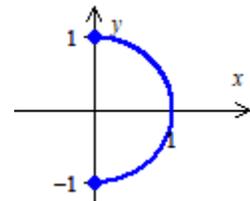
**DEFINITION:** The **inverse sine function**,  $y = \sin^{-1}(t)$ , is defined by the following:

$$\text{If } -\frac{\pi}{2} \leq y \leq \frac{\pi}{2} \text{ and } \sin(y) = t, \text{ then } y = \sin^{-1}(t).$$

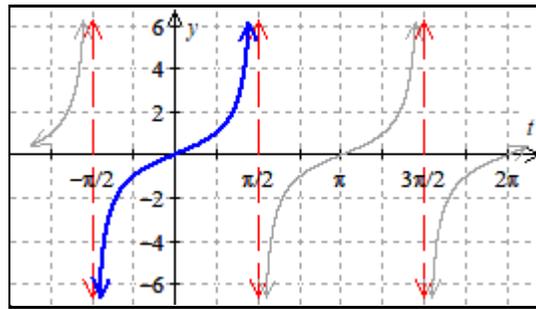
The *domain* of  $y = \sin^{-1}(t)$  is \_\_\_\_\_ (which is the range of the sine function) and the *range* of  $y = \sin^{-1}(t)$  is \_\_\_\_\_.

This function is often called the **arcsine** and is expressed as  $y = \arcsin(t)$ .

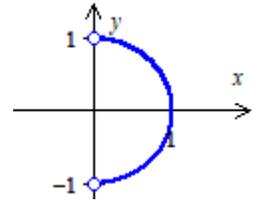
**EXAMPLE:** Evaluate  $\sin^{-1}\left(-\frac{\sqrt{2}}{2}\right)$ .



Now let's define the inverse tangent function.



A graph of  $y = \tan(t)$ .

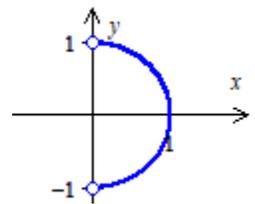


**DEFINITION:** The **inverse tangent function**,  $y = \tan^{-1}(t)$ , is defined by:

$$\text{If } -\frac{\pi}{2} < y < \frac{\pi}{2} \text{ and } \tan(y) = t, \text{ then } y = \tan^{-1}(t).$$

The *domain* of  $y = \tan^{-1}(t)$  is \_\_\_\_\_ (which is the range of the tangent function) and the *range* of  $y = \tan^{-1}(t)$  is \_\_\_\_\_. This function is often called the **arctangent** and is expressed as  $y = \arctan(t)$ .

**EXAMPLE:** Evaluate  $\tan^{-1}(-\sqrt{3})$ .



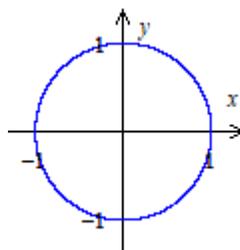
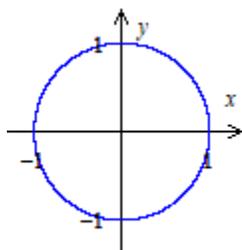
**EXAMPLE:** Evaluate the following expressions.

a.  $\sin\left(\sin^{-1}\left(\frac{\sqrt{3}}{2}\right)\right)$ .

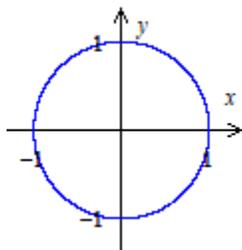
b.  $\sin^{-1}\left(\sin\left(\frac{\pi}{3}\right)\right)$ .

c.  $\sin^{-1}\left(\sin\left(\frac{2\pi}{3}\right)\right)$ .

d.  $\cos^{-1}\left(\cos\left(\frac{7\pi}{4}\right)\right)$ .



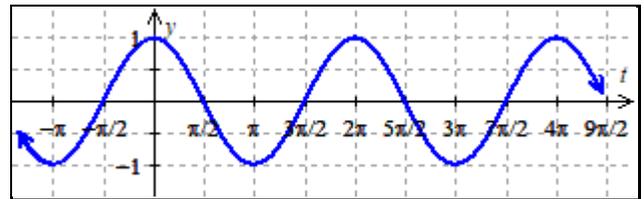
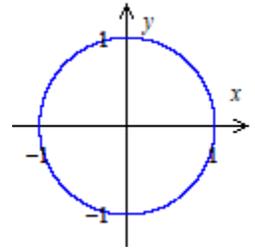
e.  $\sin^{-1}\left(\sin\left(\frac{10\pi}{11}\right)\right)$ .





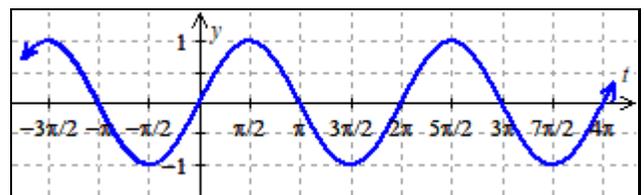
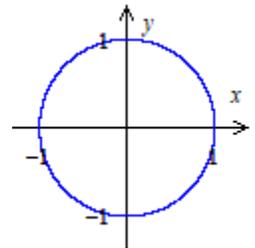
## Solving Trig Equations

**EXAMPLE:** Find all of the solutions to the equation  $8\cos(t) + 3 = -1$ .



A graph of  $y = \cos(t)$ .

**EXAMPLE:** Find all of the solutions to the equation  $4\sin(t) + 2\sqrt{3} = 0$ .

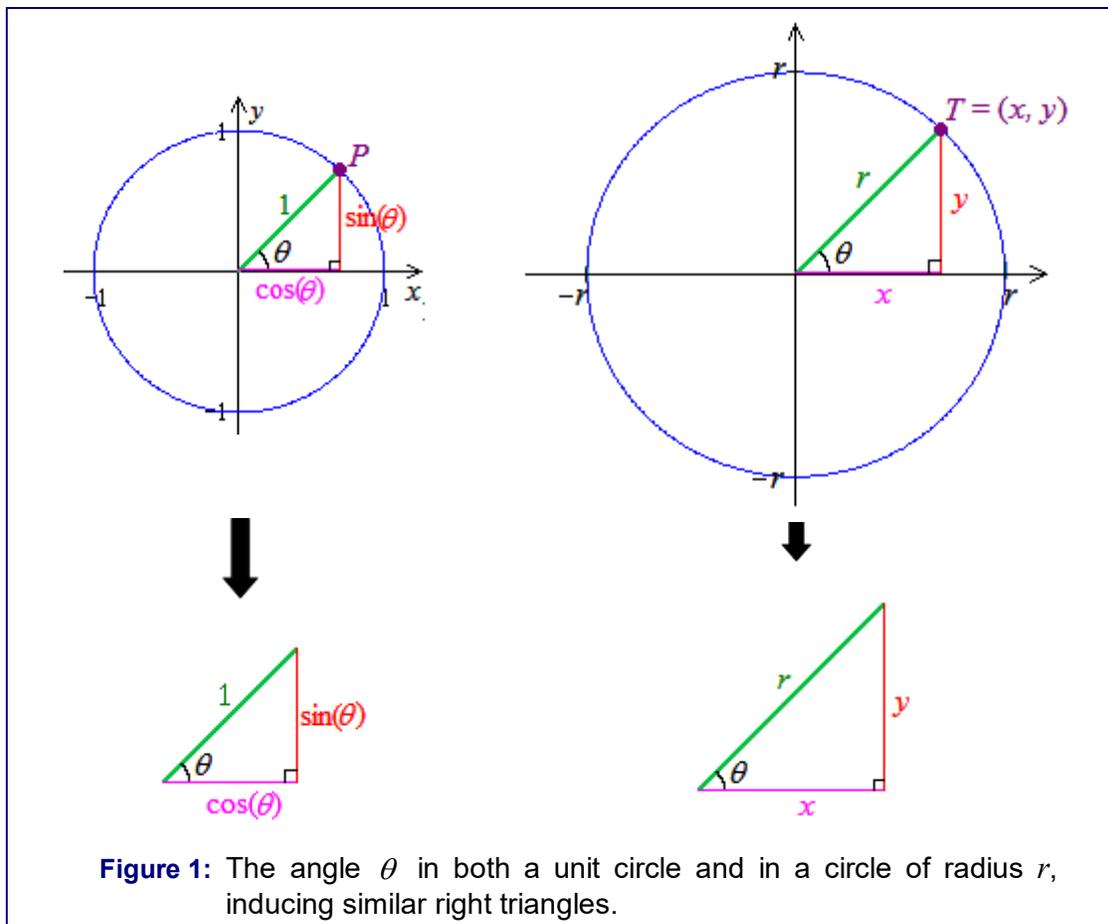


A graph of  $y = \sin(t)$ .

**EXAMPLE:** First find *all* of the solutions to the equation  $2\sqrt{2}\cos(3t) = -2$ . Then find the particular solutions on the interval  $[0, 2\pi)$ .

## Right Triangle Trigonometry

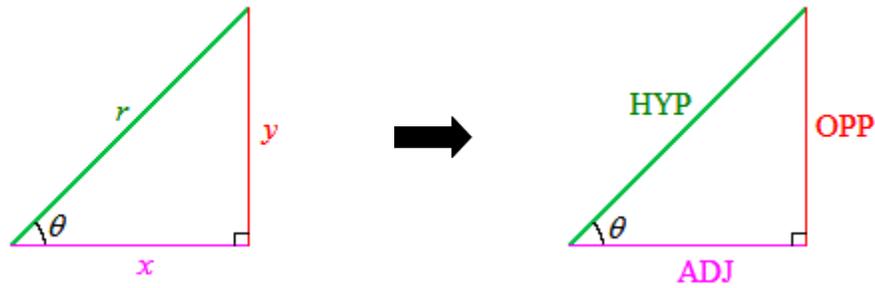
As we studied in “Intro to the Trigonometric Functions: Part 1,” if we put the same angle in the center of two circles of different radii, we can construct two *similar triangles*; see Figure 1.



We can use these similar triangles to obtain the following ratios (which we can use to derive expressions for  $\sin(\theta)$  and  $\cos(\theta)$ ):



To help remember these ratios, it's best to imagine yourself standing at angle  $\theta$  looking into the triangle. Then the side labeled  $y$  is on the **opposite** side of the triangle while the side labeled  $x$  is **adjacent** to you. We use these descriptions (as well as the fact that the side labeled  $r$  is the **hypotenuse** of the triangle) to refer to the sides of the triangles in Figure 1.



**Figure 2:** We use the terms **opposite** (or **OPP**), **adjacent** (or **ADJ**), and **hypotenuse** (or **HYP**) to refer to the sides of a right triangle.

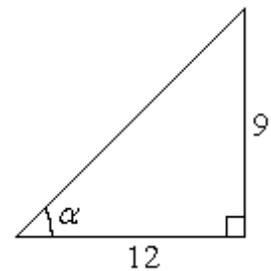
**DEFINITION:** If  $\theta$  is the angle given in the right triangles in Figure 2, then

$$\sin(\theta) = \quad \quad \quad \cos(\theta) = \quad \quad \quad \tan(\theta) =$$

Consequently, the other trigonometric functions can be defined as follows:

$$\cot(\theta) = \quad \quad \quad \sec(\theta) = \quad \quad \quad \csc(\theta) =$$

**EXAMPLE 1:** Find value for all six trigonometric functions of the angle  $\alpha$  given in the right triangle in Figure 3. (The triangle may not be drawn to scale.)



**Figure 3**

We can use the trigonometric functions, along with the Pythagorean Theorem to “**solve a right triangle**,” i.e., find the missing side-lengths and missing angle-measures for a triangle.

**EXAMPLE 2:** Solve the right triangle given in Figure 4 by finding  $A$ ,  $b$ , and  $c$ . (The triangle might not be drawn to scale.)

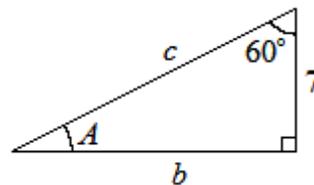


Figure 4

**EXAMPLE 3:** Solve the right triangle given in Figure 5 by finding  $c$ ,  $\alpha$ , and  $\beta$ . (The triangle might not be drawn to scale.)

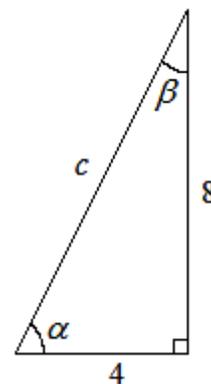


Figure 5



## The Laws of Sines and Cosines

We've studied right triangle trigonometry and learned how we can use the sine and cosine functions to obtain information about right triangles. Now we'll study how we can use the sine and cosine functions to obtain information about non-right triangles, i.e., *oblique* triangles. (Figure 1 shows a non-right (oblique) triangle since none of its angles measure  $90^\circ$ .)

The *Laws of Sines and Cosines* are **identities** because they apply to *all* triangles (i.e., right triangles and non-right triangles) but we'll only use them when we're working with non-right triangles since we already have lots of tools for right triangles.

In these class-notes, we'll state the Laws and accept/assume that they are true so that we can use them on a few examples. For their derivations, see the videos linked from the corresponding [Online Lecture Notes](#).

### THE LAW OF SINES

If a triangle's sides and angles are labeled like the triangle in Figure 1 then...

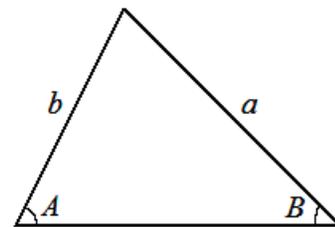


Figure 1

What does the Law of Sines imply when  $A = 90^\circ$ ?

### THE LAW OF COSINES

If a triangle's sides and angles are labeled like the triangle in Figure 2 then...

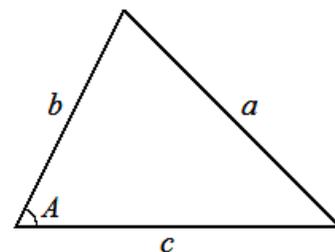
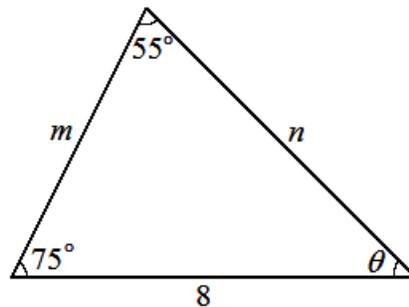


Figure 2

What does the Law of Cosines imply when  $A = 90^\circ$ ?

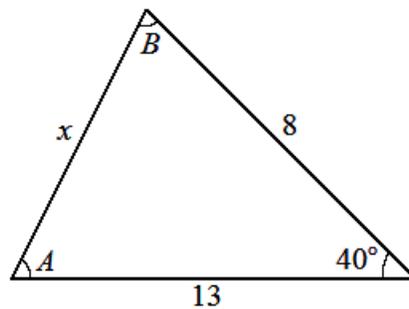
**EXAMPLE 1:** Find all of the missing angles and side-lengths of the triangle below. (The triangle may not be drawn to scale.)



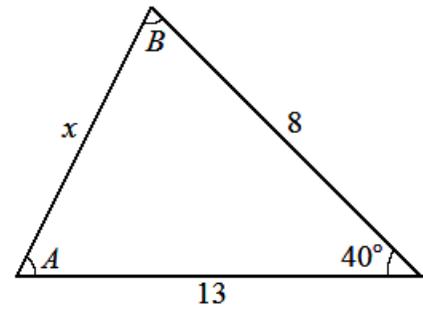
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Notice that the Law of Sines involves four parts of a triangle: two angles and the two sides opposite those angles. In order to use the Law of Sines to find a missing part of a triangle, we need to know three of these four parts of a triangle.

**EXAMPLE 2:** Find all of the missing angles and side-lengths of the triangle below. (The triangle may not be drawn to scale.)



**EXAMPLE 2 (CONT):** Find all of the missing angles and side-lengths of the triangle below.



When using the Law of Sines to find an angle, always find the smaller angle first and then use the “180 degree rule” to find the larger angle.





## Proving Trigonometric Identities

This quarter we've studied many important trigonometric identities. Because these identities are so useful, it is worthwhile to learn (or memorize) many of them (e.g., the Pythagorean Identity). But there are many other identities that aren't particularly important (so they aren't worth memorizing) but they exist and provide us an opportunity to learn another skill: proving mathematical statements. Today we will *prove trig identities*.

Proving statements is a *big* part of math – in a way, it *is* math! There are a great variety of different types of statements, and a correspondingly great variety of “techniques” for proving statements. We'll only focus on proving trig identities using one technique for proving trig identities: we'll focus on a *direct* proof that relies on the **transitive property of equality**:

**The Transitive Property of Equality**

Suppose that  $a, b, c \in \mathbb{R}$ . If  $a = b$  and  $b = c$ , then  $a = c$ .

This property may seem obvious but it's powerful: it's the property that allows us to “relax our rules” regarding equal signs. “Equal” is, by definition, a **binary operation**, so it's defined on **two** terms, so “ $a = b$ ” is defined but “ $a = b = c$ ” isn't (initially) defined: the transitive property tells us that a “triple-equation” like this is meaningful” the transitive property allows us to “streamline” the cumbersome argument in **(1)** as showing in the efficient argument in **(2)**.



To prove trig identities we'll use the argument-structure in **(2)**. This method works well for trig identities since they consist of two expressions that are always equals so, if we can *literally* show that the two sides of the trig identity are equal, we'll have a rock-solid proof. More importantly, the skill we're practicing (e.g., manipulating an expression “ $a$ ” into a different-but-equal expression “ $c$ ”) is important in Calculus.



**EXAMPLE 1:** Prove the identity  $\sin(x) = \frac{\tan(x)}{\sec(x)}$ .

**EXAMPLE 2:** Prove the identity  $\csc(x)\cos(x) = \cot(x)$ .

**EXAMPLE 3:** Prove the identity  $\cot(x) + \tan(x) = \csc(x)\sec(x)$ .

**EXAMPLE 4:** Prove the identity  $\frac{1}{1 - \cos(t)} + \frac{1}{1 + \cos(t)} = 2 \csc^2(t)$

**EXAMPLE 5:** Prove the identity  $\frac{\cos(\theta)}{1 - \sin(\theta)} = \frac{1 + \sin(\theta)}{\cos(\theta)}$ .

## Other Important Identities

First let's look at identities involving expressions of the form  $\sin(A \pm B)$  and  $\cos(A \pm B)$ . These identities allow us to calculate the sine and cosine of the sum and difference of two angles if we know the sine and cosine of the angles. (There are corresponding identities for tangent but we can use the sine and cosine identities along with the definition of tangent rather than studying another identity for tangent.) We can use these identities to find the trig values of all multiples of  $15^\circ = \frac{\pi}{12}$ .

### THE SUM AND DIFFERENCE IDENTITIES

**sine:**  $\sin(A + B) = \sin(A)\cos(B) + \cos(A)\sin(B)$   
 $\sin(A - B) = \sin(A)\cos(B) - \cos(A)\sin(B)$

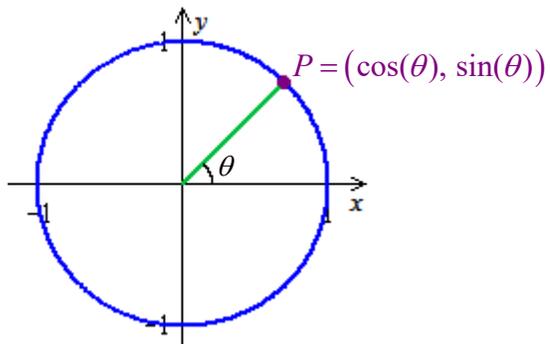
**cosine:**  $\cos(A + B) = \cos(A)\cos(B) - \sin(A)\sin(B)$   
 $\cos(A - B) = \cos(A)\cos(B) + \sin(A)\sin(B)$

**EXAMPLE 1:** Use an appropriate identity to calculate  $\cos(15^\circ)$ .

**EXAMPLE 2:** Use an appropriate identity to calculate  $\sin\left(\frac{13\pi}{12}\right)$ .

Now we'll familiarize ourselves with the double-angle identities and the half-angle identities. These identities allow us to find  $\sin(2\theta)$  &  $\cos(2\theta)$  and  $\sin\left(\frac{\theta}{2}\right)$  &  $\cos\left(\frac{\theta}{2}\right)$  if we know the values of  $\cos(\theta)$  and  $\sin(\theta)$ .

Let's start by deriving the **double-angle identity for sine**; then we'll derive the **double-angle identity for cosine**.



**DOUBLE-ANGLE IDENTITIES****sine :****cosine :**

**EXAMPLE 1:** If  $\cos(A) = \frac{1}{3}$ , where  $\frac{3\pi}{2} < A < 2\pi$ , find  $\cos(2A)$ ,  $\sin(2A)$ , and  $\tan(2A)$ .

We can use the double-angle identities for cosine to derive **half-angle identities**.

Recall this double-angle identity for cosine:  $\cos(2\theta) = 1 - 2\sin^2(\theta)$ . We can use this identity to find a half-angle identity for sine:

We can use  $\cos(2\theta) = 2\cos^2(\theta) - 1$  to find a half-angle identity for cosine:

### HALF-ANGLE IDENTITIES

**sine :**

**cosine :**

**When using the half-angle identities, you need to decide which sign to use by determining which quadrant  $\frac{A}{2}$  falls in.**

**EXAMPLE 2:** If  $\cos(A) = \frac{1}{3}$ , where  $\frac{3\pi}{2} < A < 2\pi$ . Find  $\cos\left(\frac{A}{2}\right)$  and  $\sin\left(\frac{A}{2}\right)$ .

**EXAMPLE 3:** Use a half-angle identity to find  $\cos(15^\circ)$ .



## Introduction to Polar Coordinates

We are all comfortable using rectangular (i.e., Cartesian) coordinates to describe points on the plane. In Figure 1 let's plot the point  $P = (\sqrt{3}, 1)$  on the rectangular coordinate plane:

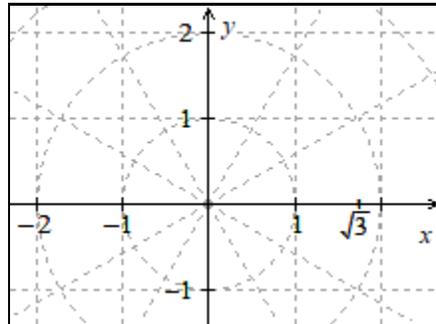
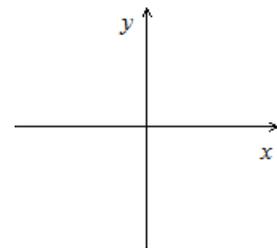


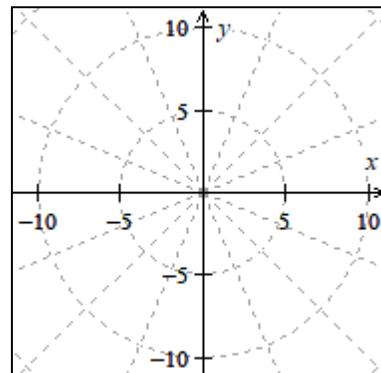
Figure 1

Instead of using these *rectangular* coordinates, we can use a *circular* coordinate system to describe points on the plane, i.e., we can use the **polar coordinate system**. Ordered pairs in polar coordinates have form  $(r, \theta)$  where  $r$  represents the point's distance from the origin and  $\theta$  represents the angular displacement of the point with respect to the positive  $x$ -axis. Let's find the polar coordinates that describe  $P = (\sqrt{3}, 1)$ .

The rectangular coordinates  $(x, y)$  are equivalent to the  $(r, \theta)$  polar coordinates such that:

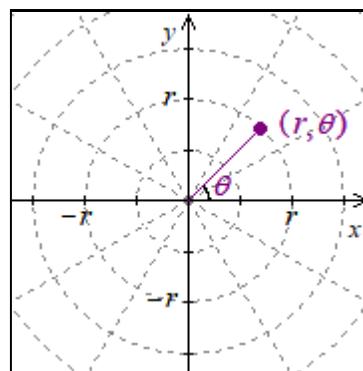


**EXAMPLE:** Plot the point  $A = \left(10, \frac{5\pi}{4}\right)$  on the polar coordinate plane below and determine the rectangular coordinates of point  $A$ .



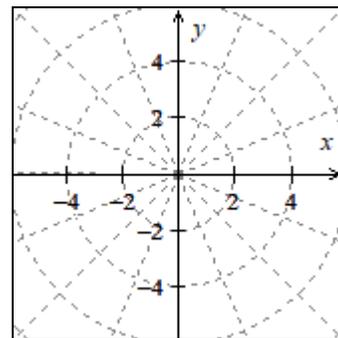
Plot  $A = \left(10, \frac{5\pi}{4}\right)$ .

The polar coordinates  $(r, \theta)$  are equivalent to the following rectangular coordinates:



What happens if  $r < 0$ ?

**EXAMPLE:** Plot the point  $B = \left(-4, \frac{2\pi}{3}\right)$  on the polar coordinate plane below and list a few other ordered pairs that are plotted at the same location.

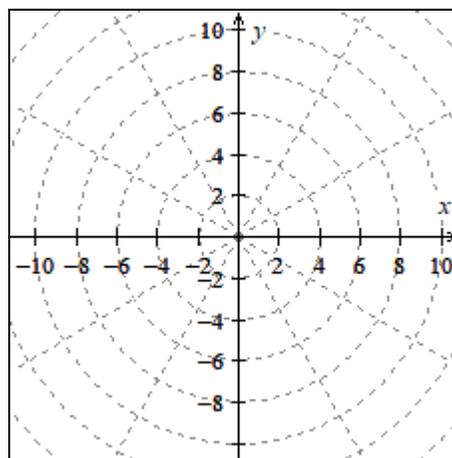


Plot  $B = \left(-4, \frac{2\pi}{3}\right)$ .

## Graphing Polar Functions

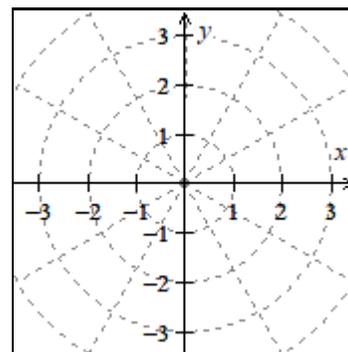
Now let's graph polar functions, i.e., functions that involve polar coordinates. These functions will have form  $r = f(\theta)$ , so the input,  $\theta$ , is an angle and the output,  $r$ , is the distance from the origin. **Notice that in a polar ordered pair,  $(r, \theta)$ , the *output* variable,  $r$ , is the **first coordinate** and the *input* variable,  $\theta$ , is the **second coordinate** which is a **different order** than rectangular ordered pairs of the form  $(x, y)$  in which the *input* variable is the first coordinate and the *output* variable is the second coordinate.**

**EXAMPLE:** Sketch a graph of the polar function  $r = \theta$ .



Sketch a graph  $r = \theta$ .

**EXAMPLE:** Sketch a graph of the polar function  $r = 3$ .

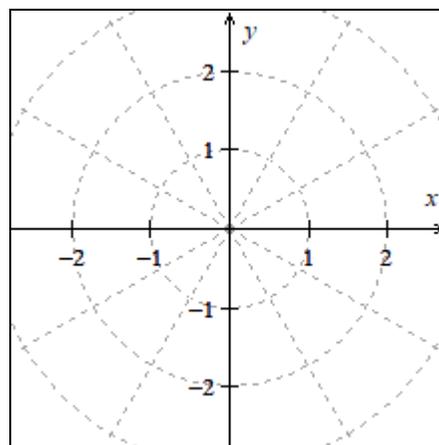


Sketch a graph  $r = 3$ .

**EXAMPLE:** Sketch a graph of the  $r = 2 \sin(2\theta)$  on the polar coordinate plane.

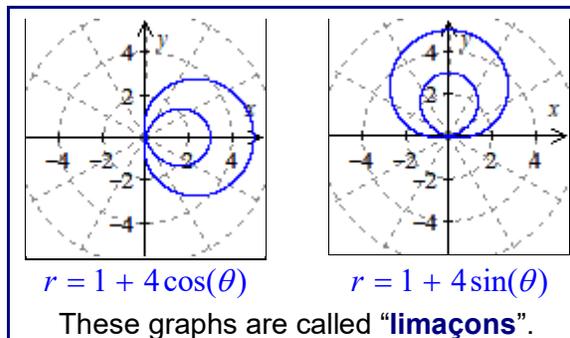
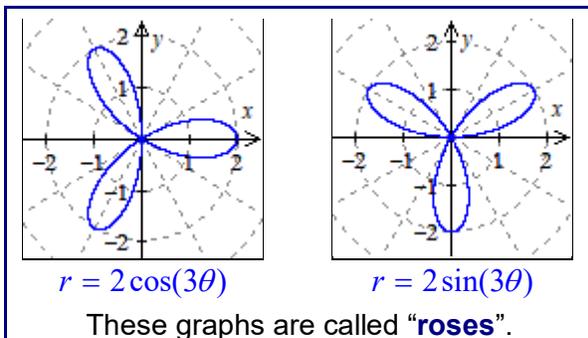
To sketch the graph of  $r = 2 \sin(2\theta)$ , let's find some ordered pairs that satisfy the function.

$\theta$	$r = 2 \sin(2\theta)$	$(r, \theta)$
0		
$\frac{\pi}{12}$		
$\frac{\pi}{6}$		
$\frac{\pi}{4}$		
$\frac{\pi}{3}$		
$\frac{\pi}{2}$		
$\frac{2\pi}{3}$	$-\sqrt{3} \approx -1.7$	
$\frac{3\pi}{4}$	-2	
$\frac{5\pi}{6}$	$-\sqrt{3} \approx -1.7$	
$\pi$	0	
$\frac{7\pi}{6}$	$\sqrt{3} \approx 1.7$	
$\frac{5\pi}{4}$	2	
$\frac{4\pi}{3}$	$\sqrt{3} \approx 1.7$	
$\frac{3\pi}{2}$	0	
$\frac{5\pi}{3}$	$-\sqrt{3} \approx -1.7$	
$\frac{7\pi}{4}$	-2	
$\frac{11\pi}{6}$	$-\sqrt{3} \approx -1.7$	



Sketch a graph  $r = 2 \sin(2\theta)$ .

Below are the graphs of a few other functions defined via polar coordinates.



**EXAMPLE:** Convert the rectangular equation  $y = 4x - 3$  into an equivalent equation in polar coordinates.

**EXAMPLE:** Convert the polar equation  $r = 3\sin(\theta)$  into an equivalent equation in rectangular coordinates.



## Complex Numbers and Polar Coordinates

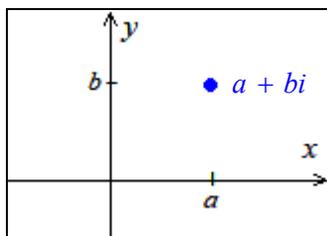
Recall from Section I: Chapter 0 the definition of the set of complex numbers:

$$\mathbb{C} = \{x \mid x = a + bi \text{ and } a, b \in \mathbb{R} \text{ and } i = \sqrt{-1}\}.$$

You've probably seen complex numbers in a course like MTH 95 or Algebra 2 when solving quadratic equations like  $x^2 - 4x + 13 = 0$ :

For a complex number of the form  $a + bi$ , its *real part* is  $a$  and its *imaginary part* is  $b$ .

Because a complex number has *two* parts, we can use the *two dimensional* rectangular coordinate plane to plot complex numbers. We use the horizontal axis to represent the real part of the number and the vertical axis to represent the complex part of the number. Thus, the complex number  $a + bi$  can be represented by the point  $(a, b)$  on the rectangular coordinate plane; see Figure 1.



**Figure 1**

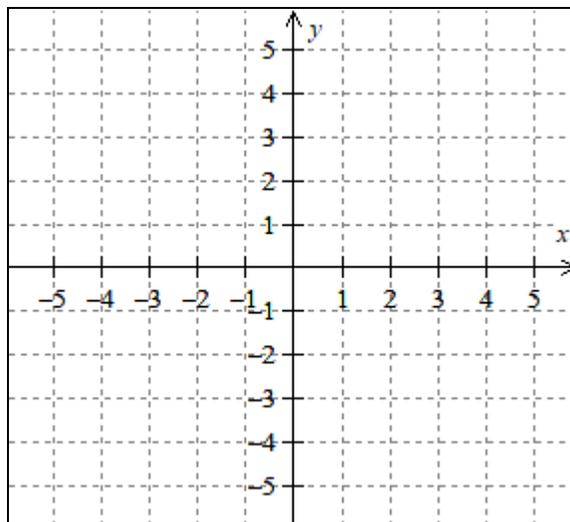
**EXAMPLE:** Plot the following complex numbers on the coordinate plane in Figure 2.

**a.**  $s = 2 + 5i$

**b.**  $t = \frac{3}{2} - 3i$

**c.**  $u = 3i$

**d.**  $v = -4$



**Figure 2**

As we've studied, the rectangular ordered pair  $(a, b)$  can be represented in polar coordinates  $(r, \theta)$  where  $r$  represents the distance the point is from the origin and  $\theta$  represents the angle between the positive  $x$ -axis and the segment connecting the origin and the point; see Figure 3. Let's recall how we can find  $r$  and  $\theta$  when we know  $a$  and  $b$ :

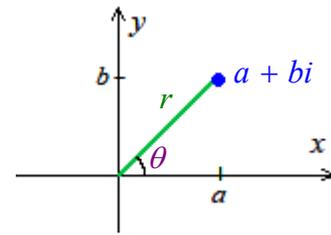


Figure 3

Let's also recall how we can find  $a$  and  $b$  when we know  $r$  and  $\theta$ :

Using this information, we can write the complex number  $a + bi$  in terms of  $r$  and  $\theta$ :

Now we can establish a surprising connection between exponential function  $y = e^x$  and complex numbers: Euler's Formula. (If you continue studying mathematics and take a calculus sequence, you have an opportunity to see why this equation is true but, for now, you need to just accept it and learn to work with it.)

#### EULER'S FORMULA

$$e^{i\theta} = \cos(\theta) + \sin(\theta) \cdot i$$

By multiplying both sides of Euler's formula by  $r$ , we obtain the following formula that allows us to write any complex number in **polar form**.

The **polar form** of the complex number  $z = a + bi$  is  $z = re^{i\theta}$ :

**EXAMPLE:** Express the complex number  $z = 6e^{i\frac{5\pi}{6}}$  in rectangular form  $z = a + bi$ .

**EXAMPLE:** Express the complex number  $z = 3 - 3i$  in polar form  $z = re^{i\theta}$ .



## Introduction to Vectors

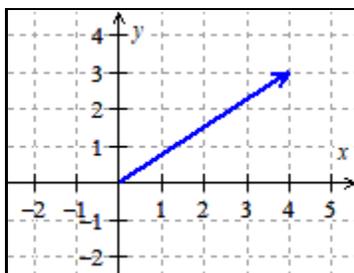
Vectors are mathematical objects used to represent physical quantities like velocity, force, and displacement. Unlike ordinary numbers (or **scalars**), vectors have *both* magnitude and direction. So, for example, we can use a vector to describe the velocity of an object (i.e., the speed *and* direction).

**DEFINITION:** A **vector** is a mathematical object that has both a *magnitude* (i.e., size) and a *direction*.

In order to distinguish between vectors from scalars (i.e., numbers) we need to use a different notation to denote vectors. In this class, we will use a small arrow above the vector name to denote a vector, so that  $\vec{v}$  and  $\vec{s}$  represent vectors while  $v$  and  $s$  represent scalars.

In this class we will focus on **two-dimensional vectors**. A two-dimensional vector can be represented by an **arrow** on the coordinate plane. The **length** of the arrow represents the **magnitude** of the vector and the **direction** of the arrow represents the direction of the vector. (We traditionally use the **angle between the positive  $x$ -axis and the arrow** to describe the **direction** of the vector.)

**EXAMPLE 1:** The vector  $\vec{v}$  is depicted as an arrow on the coordinate plane in Figure 1.



**Figure 1:** Arrow representing vector  $\vec{v}$ .

The **tip** of the vector is where the arrow ends and the **tail** of the vector is where the arrow begins. Thus, the tip of  $\vec{v}$  is at the point  $(4, 3)$  and the tail of the vector is at the origin,  $(0, 0)$ .

As mentioned above, the **length** of the arrow represents the **magnitude** of the vector. We denote the magnitude of vector  $\vec{v}$  by  $\|\vec{v}\|$ . To find the magnitude of  $\vec{v}$ , we need to find the length of the arrow; we can do this by thinking of the arrow as being the hypotenuse of a right-triangle with side lengths 4 and 3 and then use the Pythagorean Theorem to find  $\|\vec{v}\|$ :

We can find the angle between the positive  $x$ -axis and the arrow to describe the **direction** of the vector. We've denoted this angle by  $\theta$  in Figure 2.

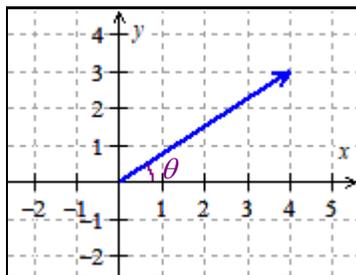


Figure 2

We can use the trigonometry that we studied earlier this quarter to find  $\theta$ :

Although the magnitude and direction of the vector describe it completely, it is often useful to describe a vector by using its **horizontal and vertical components**. The *horizontal component* of  $\vec{v}$  in Figure 2 is 4 units and a *vertical component* of vector  $\vec{v}$  is 3 units. Thus, we say that the **component form of vector  $\vec{v}$**  is  $\langle 4, 3 \rangle$ .

It's important to recognize that we could translate this vector anywhere in the coordinate plane and it would still be the same vector. For example, all of the arrows in Figure 3 represent  $\vec{v}$  since all of these vectors have a horizontal component of 4 units and a vertical component of 3 units.

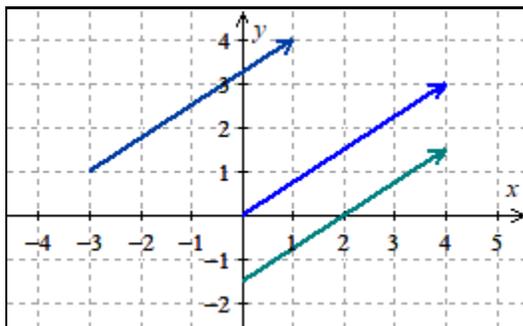


Figure 3: Three copies of  $\vec{v}$ .

## Vector Operations

We can **multiply any vector by a scalar** (i.e., a number) and we can **add or subtract any two vectors**.

When we **multiply a vector by a scalar**, we simply multiply the respective components of the vector by the scalar. Thus, if  $\vec{a} = \langle a_1, a_2 \rangle$  and  $k \in \mathbb{R}$ , then  $k\vec{a} = \langle ka_1, ka_2 \rangle$ .

**EXAMPLE 2:** Let  $\vec{v} = \langle 4, 3 \rangle$  (from Example 1). Find and draw vectors  $\vec{m} = 2\vec{v}$  and  $\vec{n} = -2\vec{v}$ .

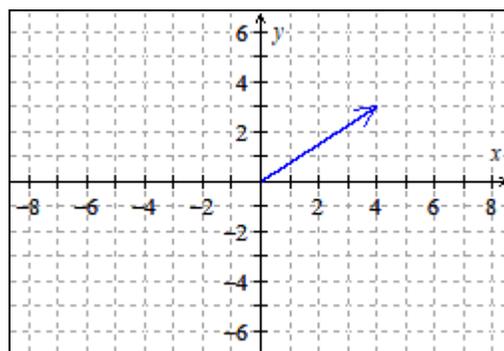


Figure 4: Vector  $\vec{v}$ .

If  $\vec{a} = \langle a_1, a_2 \rangle$  is a vector and  $k \in \mathbb{R}$  then  $k\vec{a} = \langle ka_1, ka_2 \rangle$  has magnitude  $|k| \cdot \|\vec{a}\|$ .  
 If  $k > 0$  then  $k \cdot \vec{a}$  points in the same direction as  $\vec{a}$ ; if  $k < 0$  then  $k \cdot \vec{a}$  points in the opposite direction as  $\vec{a}$ .

**EXAMPLE 3:** Suppose that the vector  $\vec{m}$  makes an angle of  $37^\circ$  with respect to the positive  $x$ -axis and  $\|\vec{m}\| = 20$ . Represent  $\vec{m}$  in component form.

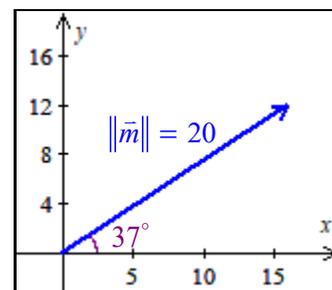


Figure 5: Vector  $\vec{m}$

In general, if vector  $\vec{v}$  makes an angle  $\theta$  with the positive  $x$ -axis then, in component form,

When we **add**, we simply add the respective components of the vectors. Thus, if  $\vec{a} = \langle a_1, a_2 \rangle$  and  $\vec{b} = \langle b_1, b_2 \rangle$ , then  $\vec{a} + \vec{b} = \langle a_1 + b_1, a_2 + b_2 \rangle$  and  $\vec{a} - \vec{b} = \langle a_1 - b_1, a_2 - b_2 \rangle$

**EXAMPLE 4:** Let  $\vec{v} = \langle 4, 3 \rangle$  (from Example 1) and  $\vec{s} = \langle 2, -6 \rangle$ . Find  $\vec{v} + \vec{s}$ .

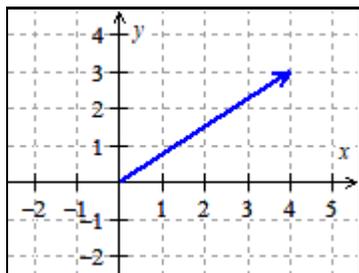


Figure 6: Vector  $\vec{v}$ .

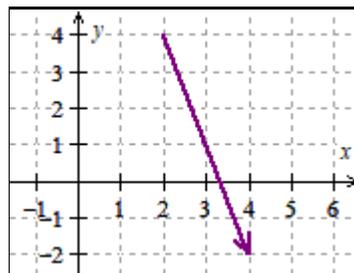


Figure 7: Vector  $\vec{s}$ .

Let's find  $\vec{v} + \vec{s}$ :

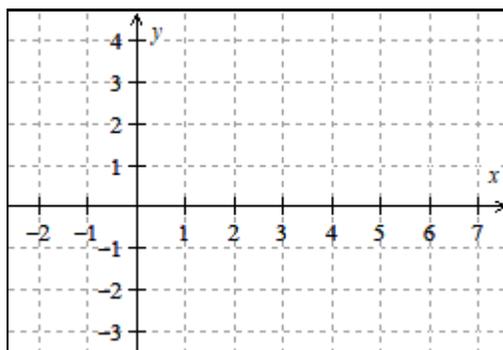


Figure 8: Adding vectors graphically.

We can also add vectors by using arrows on a coordinate plane:

### Properties of Vector Addition and Scalar Multiplication

If  $\vec{u}$ ,  $\vec{v}$ , and  $\vec{w}$  are vectors and  $a$  and  $b$  are scalars (i.e.,  $a, b \in \mathbb{R}$ ) then the following properties hold true:

1. **Commutativity of Vector Addition:**  $\vec{u} + \vec{v} = \vec{v} + \vec{u}$
2. **Associativity of Vector Addition:**  $(\vec{u} + \vec{v}) + \vec{w} = \vec{u} + (\vec{v} + \vec{w})$
3. **Associativity of Scalar Multiplication:**  $a(b\vec{v}) = (ab)\vec{v}$
4. **Distributivity:**  $(a + b)\vec{v} = a\vec{v} + b\vec{v}$  and  $a(\vec{u} + \vec{v}) = a\vec{u} + a\vec{v}$
5. **Identities:**  $\vec{v} + \vec{0} = \vec{v}$  and  $1 \cdot \vec{v} = \vec{v}$

In order to facilitate the communication and manipulation of vectors, it is useful to consider **unit vectors**.

**DEFINITION:** A **unit vector** is a vector whose magnitude is 1 unit. So if  $\vec{a}$  is a unit vector then  $\|\vec{a}\| = 1$ .

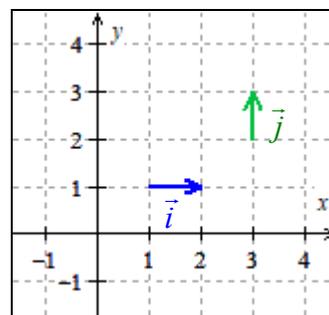
The **standard unit vectors** are the unit vectors that point in the horizontal and vertical directions.

**DEFINITION:**

The vector  $\vec{i}$  is the unit vector that points in the **positive horizontal direction**. Since its horizontal component is 1 and its vertical component is 0, we see that  $\vec{i} = \langle 1, 0 \rangle$ .

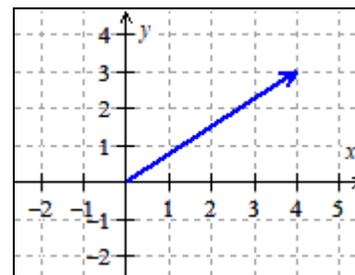
The vector  $\vec{j}$  is the unit vector that points in the **positive vertical direction**. Since its horizontal component is 0 and its vertical component is 1, we see that  $\vec{j} = \langle 0, 1 \rangle$ .

Note that since they are *unit vectors*,  $\|\vec{i}\| = 1$  and  $\|\vec{j}\| = 1$ .



**Figure 9:** Unit vectors  $\vec{i}$  and  $\vec{j}$ .

We can use vectors  $\vec{i}$  and  $\vec{j}$  to describe all other two-dimensional vectors. For example, we can describe  $\vec{v} = \langle 4, 3 \rangle$  (from Example 1) using vectors  $\vec{i}$  and  $\vec{j}$ : along with scalar multiplication and vector addition:



**Figure 10:** Vector  $\vec{v}$ .

In general, if  $\vec{a} = \langle a_1, a_2 \rangle$  is a vector, then \_\_\_\_\_.



## The Dot Product

We've studied how to add and subtract vectors and how to multiply vectors by scalars. Now we'll study how to multiply one vector by another. This type of multiplication is called the **dot product**. Since we are focusing on two-dimensional vectors in this class, we will define the dot product in terms of two-dimensional vectors:

**DEFINITION:** If  $\vec{u} = \langle u_1, u_2 \rangle$  and  $\vec{v} = \langle v_1, v_2 \rangle$ , then **the dot product of  $\vec{u}$  and  $\vec{v}$** , denoted  $\vec{u} \cdot \vec{v}$ , is defined as follows:

$$\vec{u} \cdot \vec{v} = u_1v_1 + u_2v_2$$

Thus, to compute the dot product of two vectors, we simply multiply the horizontal components of the two vectors and the vertical components of the two vectors and then add the results. It is important to note that the dot product produces a **scalar**.

**EXAMPLE 1:** If  $\vec{a} = \langle 3, -9 \rangle$  and  $\vec{b} = \langle 6, -1 \rangle$ , find  $\vec{a} \cdot \vec{b}$ .

### Properties of the Dot Product

If  $\vec{u}$ ,  $\vec{v}$ , and  $\vec{w}$  are vectors then the following properties hold true:

1.  $\vec{u} \cdot \vec{v} = \vec{v} \cdot \vec{u}$  (commutative property)
2.  $\vec{u} \cdot (\vec{v} + \vec{w}) = \vec{u} \cdot \vec{v} + \vec{u} \cdot \vec{w}$  (distributive property)
3.  $\vec{v} \cdot \vec{v} = \|\vec{v}\|^2$
4.  $\vec{u} \cdot \vec{v} = \|\vec{u}\| \cdot \|\vec{v}\| \cos(\theta)$  where  $\theta$  is the angle between  $\vec{u}$  and  $\vec{v}$ .

The dot product can be used to find the angle between two vectors.

**EXAMPLE 2:** Find the angle between vectors  $\vec{a} = \langle 3, -9 \rangle$  and  $\vec{b} = \langle 6, -1 \rangle$  from Example 1.

---

**EXAMPLE 3:** If the angle between  $\vec{u}$  and  $\vec{v}$  is  $\theta = 90^\circ$  (i.e., if  $\vec{u}$  and  $\vec{v}$  are perpendicular), find  $\vec{u} \cdot \vec{v}$ .

**EXAMPLE 4:** If  $\vec{u}$  and  $\vec{v}$  are non-zero vectors and  $\vec{u} \cdot \vec{v} > 0$ , what can you say about the angle  $\theta$  between vectors  $\vec{u}$  and  $\vec{v}$ . What if  $\vec{u} \cdot \vec{v} < 0$ ?

Now we'll prepare to derive  $\vec{u} \cdot \vec{v} = \|\vec{u}\| \cdot \|\vec{v}\| \cos(\theta)$ . We'll need to use the **difference of two vectors** so first let's explore that:

**EXAMPLE 5:** Let  $\vec{v} = \langle 4, 3 \rangle$  and  $\vec{s} = \langle 2, -6 \rangle$ ; find  $\vec{v} - \vec{s}$ .

We can also subtract vectors by using arrows on the coordinate plane. Notice that  $\vec{v} - \vec{s} = \vec{v} + (-\vec{s})$ : so in Figure 1 we can subtract  $\vec{s}$  from  $\vec{v}$  by adding  $-\vec{s}$  to  $\vec{v}$ :

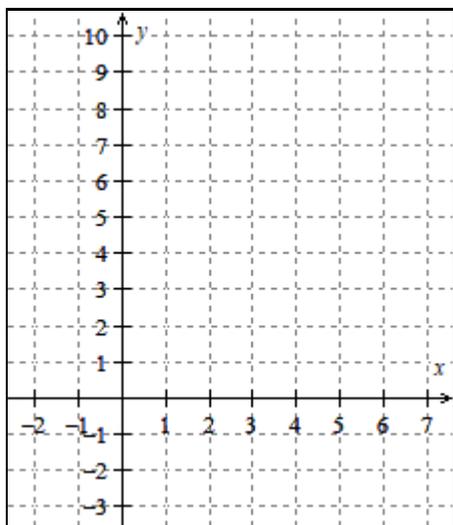


Figure 1

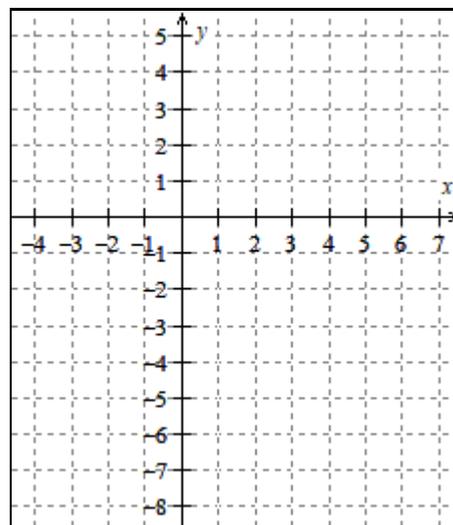


Figure 2

Interestingly,  $\vec{v} - \vec{s}$  is the vector that we need to add to  $\vec{s}$  in order to create  $\vec{v}$ : we can see this symbolically and then use it obtain another way to draw  $\vec{v} - \vec{s}$  in Figure 2.

We'll also need to use the identity  $\vec{v} \cdot \vec{v} = \|\vec{v}\|^2$  so let's prove it by computing  $\vec{v} \cdot \vec{v}$  for a generic vector  $\vec{v} = \langle v_1, v_2 \rangle$  and showing that the result is equal to  $\|\vec{v}\|^2$  (this proof will have the same structure as our proofs of trig identities).



Now we're ready to derive  $\vec{u} \cdot \vec{v} = \|\vec{u}\| \cdot \|\vec{v}\| \cos(\theta)$  where  $\theta$  is the angle between  $\vec{u}$  and  $\vec{v}$ :

First let's draw two vectors  $\vec{u}$  and  $\vec{v}$  so that  $\theta$  is the angle between the vectors:

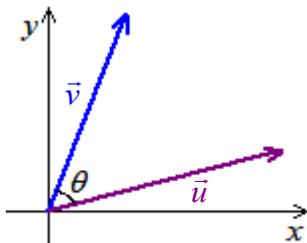
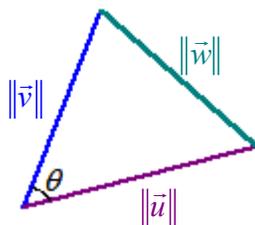


Figure 3

Now let's construct the vector  $\vec{w} = \vec{v} - \vec{u}$ . Recall that we can obtain the vector  $\vec{v} - \vec{u}$  by drawing an arrow that starts at the tip of  $\vec{u}$  and ends at the tip of  $\vec{v}$ .

If we think of the arrows as being line segments instead of arrows, we have a triangle with side lengths  $\|\vec{u}\|$ ,  $\|\vec{v}\|$ , and  $\|\vec{w}\|$  and angle  $\theta$  opposite the side  $\|\vec{w}\|$ .



**Figure 4**

Now we can use the Law of Cosines to obtain an equation that relates the magnitudes of the vectors and the angle  $\theta$ .

We can use this equation to obtain the statement given in fourth property in the table above. First, let's find  $\|\vec{w}\|^2$ . Recall that  $\vec{w} = \vec{v} - \vec{u}$ . So...

We can now substitute this expression for  $\|\vec{w}\|^2$  in the equation we found above, and simplify to obtain  $\vec{u} \cdot \vec{v} = \|\vec{u}\| \cdot \|\vec{v}\| \cos(\theta)$ :



## A Summary via Examples

**EXAMPLE 1a:** Find  $B$  and  $c$  in the right triangle given in Figure 1. (The triangle might not be drawn to scale.)

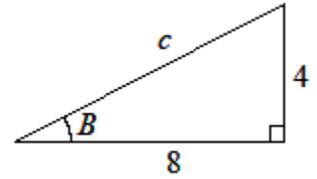


Figure 1

**EXAMPLE 1b:** Find  $a$  and  $b$  in the right triangle given in Figure 2. (The triangle might not be drawn to scale.)

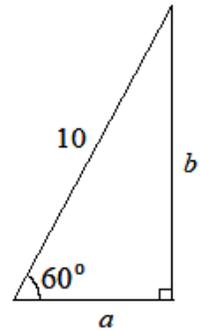
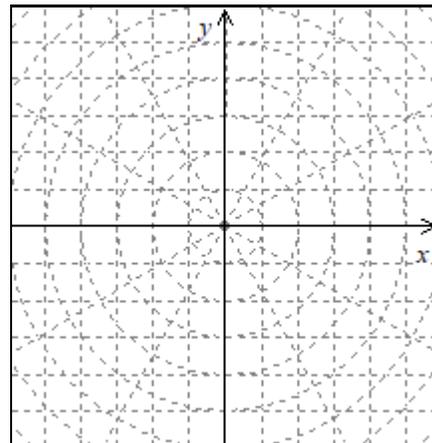
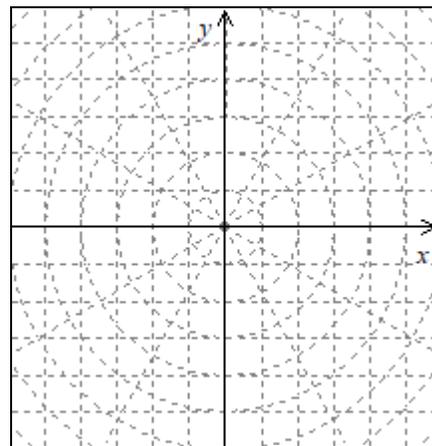


Figure 2

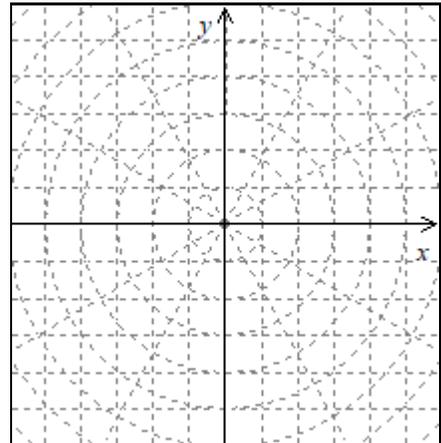
**EXAMPLE 2a:** Translate the rectangular ordered pair  $(-8, -4)$  into polar coordinates  $(r, \theta)$ .



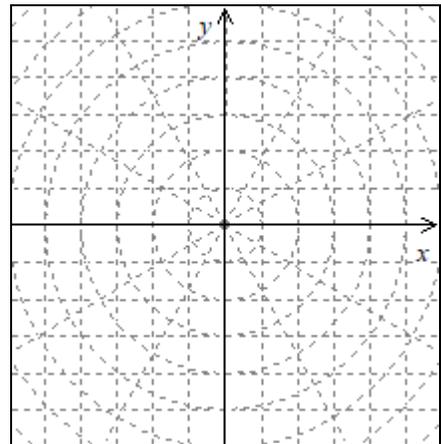
**EXAMPLE 2b:** Translate the polar ordered pair  $(10, \frac{4\pi}{3})$  into rectangular coordinates  $(x, y)$ .



**EXAMPLE 3a:** Find the polar form,  $z = r \cdot e^{i\theta}$ , of the complex number  $z = -8 + 4i$ .



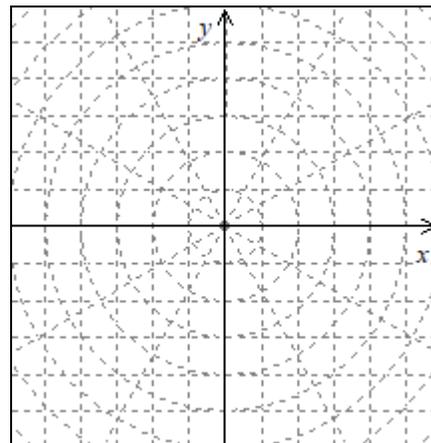
**EXAMPLE 3b:** Find the rectangular form,  $z = a + bi$ , of the complex number  $z = 10 \cdot e^{i\frac{2\pi}{3}}$ .



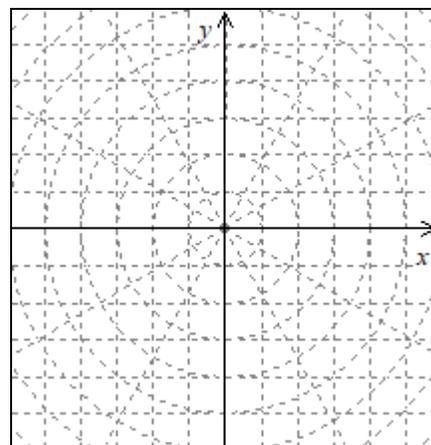
**EXAMPLE 4a:** If  $\vec{v} = 8\vec{i} - 4\vec{j}$ , find

(1) the direction of  $\vec{v}$  (measured in degrees with respect to the positive  $x$ -axis)

(2)  $\|\vec{v}\|$



**EXAMPLE 4b:** Find the components of the vector  $\vec{w}$  if  $\|\vec{w}\| = 10$  and  $\vec{w}$  has a direction of  $300^\circ$  with respect to the positive  $x$ -axis.



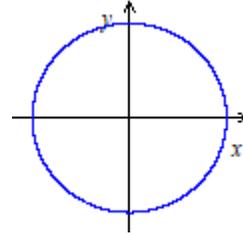




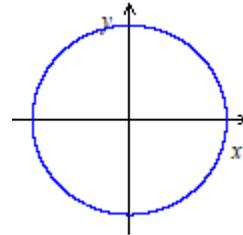
## Week 1 Practice Worksheet

### Angles, Arc-length, and Periodic Functions

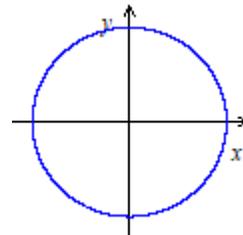
1. a. Draw  $140^\circ$  in standard position on the provided coordinate plane.



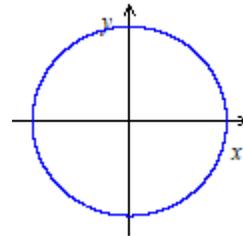
- b. Draw  $-250^\circ$  in standard position on the provided coordinate plane.



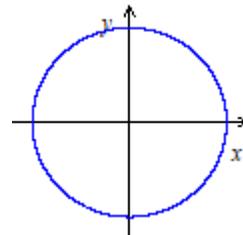
- c. Draw  $\frac{4\pi}{5}$  radians in standard position on the provided coordinate plane.



- d. Draw 4 radians in standard position on the provided coordinate plane.



- d. Draw  $-3$  radians in standard position on the provided coordinate plane.



2. The Greek letters  $\theta$  and  $\phi$  are often used as variables in mathematics. They are ***different*** symbols so it's important to distinguish between them. Which of these symbols is pronounced "phi"? And which is pronounced "theta"?
3. a. Convert  $\frac{\pi}{10}$  radians into degrees.
- b. Convert 4 radians into degrees.
- c. Convert  $10^\circ$  into radians.
- d. Convert  $140^\circ$  into radians.
- e. Convert  $1200^\circ$  into radians.

4. a. Find both a positive and a negative angle that are coterminal with  $140^\circ$ .  
(Answer in degrees.)

b. Find both a positive and a negative angle that are coterminal with  $-\frac{5\pi}{8}$ .  
(Answer in radians.)

c. Represent infinitely many different angles that are coterminal with  $70^\circ$ .

d. Represent infinitely many different angles that are coterminal with  $\frac{3\pi}{5}$ .

5. Complete the table below.

$\theta$ (degrees)	$0^\circ$	$30^\circ$		$60^\circ$	$90^\circ$		$270^\circ$	$360^\circ$	
$\theta$ (radians)			$\frac{\pi}{4}$			$\pi$			$20\pi$

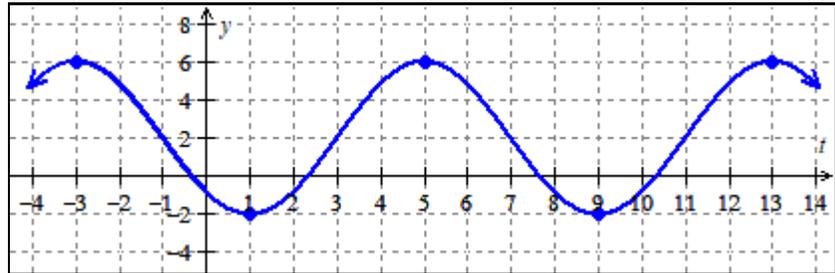
6. What is the length of the arc spanned by the angle 4 radians on a circle of radius 20 yards?

7. What is the length of the arc spanned by the angle  $25^\circ$  on a circle of radius 30 inches?

8. What is the length of the arc spanned by the angle  $\frac{4\pi}{5}$  radians on a circle of radius 15 feet?

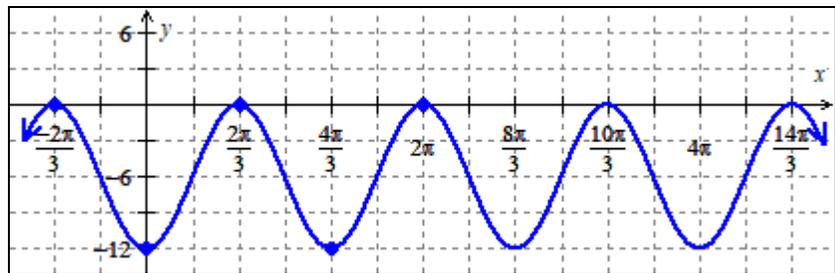
9. What is the length of the arc spanned by the angle  $135^\circ$  on a circle of radius 8 meters?

10. Determine the period, midline and amplitude of the function  $y = f(t)$  graphed below. Note that the following points are on the graph:  $(-3, 6)$ ,  $(1, -2)$ ,  $(5, 6)$ ,  $(9, -2)$ , and  $(13, 6)$ .



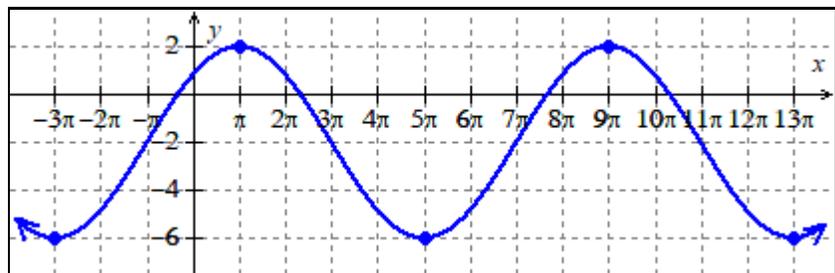
The graph of  $y = f(t)$ .

11. Determine the period, midline and amplitude of the function  $y = g(t)$  graphed below. Note that the following points are on the graph:  $(-\frac{2\pi}{3}, 0)$ ,  $(0, -12)$ ,  $(\frac{2\pi}{3}, 0)$ , and  $(\frac{4\pi}{3}, -12)$ .



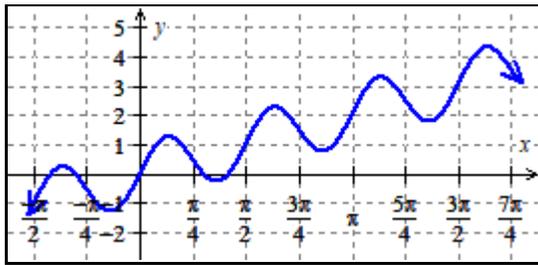
The graph of  $y = g(t)$ .

12. Determine the period, midline and amplitude of the function  $y = p(x)$  graphed below. Note that the following points are on the graph:  $(-3\pi, -6)$ ,  $(\pi, 2)$ ,  $(5\pi, -6)$ , and  $(9\pi, 2)$ .

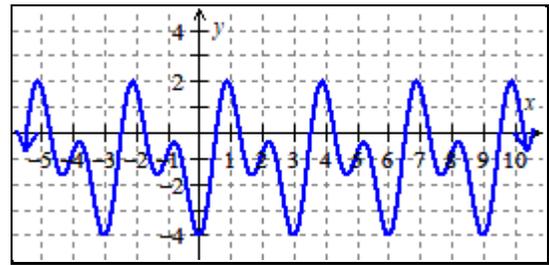


The graph of  $y = p(x)$ .

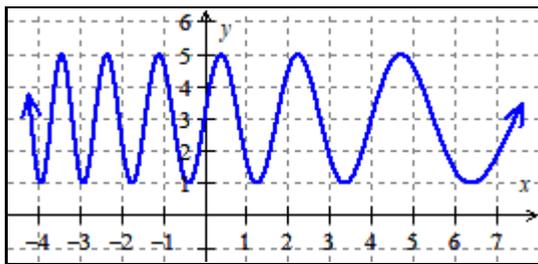
13. Determine which of the functions graphed below are periodic functions and find the period, midline, and amplitude of the periodic functions.



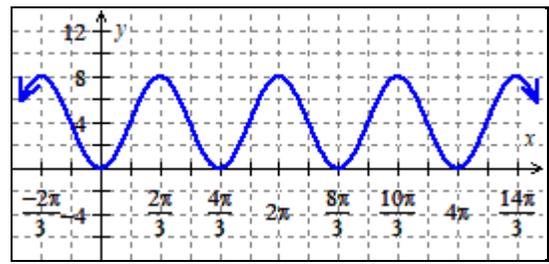
$y = A(x)$



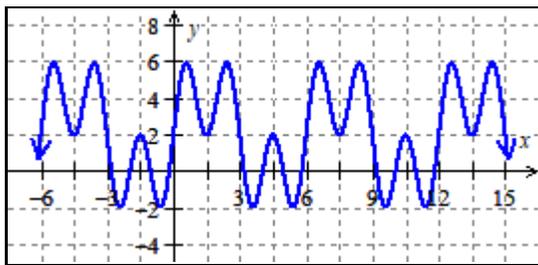
$y = B(x)$



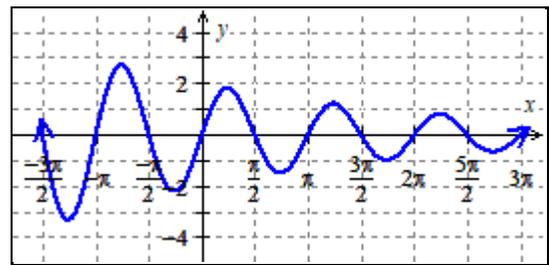
$y = C(x)$  is



$y = D(x)$



$y = E(x)$



$y = F(x)$

14. There's a Ferris wheel with a diameter of 80 feet. The wheel rotates at a constant rate, and completes a full rotation every 20 minutes. The wheel is lifted 10 feet above the ground level, and passengers load into carriages at the lowest point in the wheel's travel (so passengers start their trip 10 feet above the ground). Determine the period, midline and amplitude of the function that associates amount of time a passenger spends in a carriage travelling around the wheel with the height (in feet) above the ground of such a passenger.

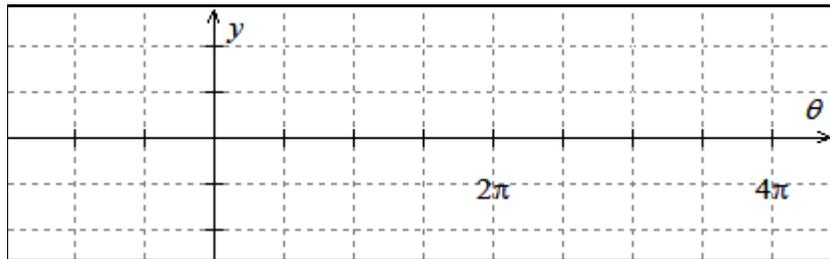
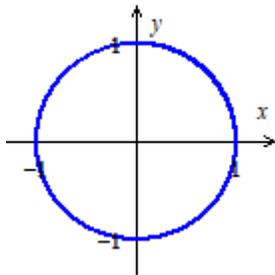


## Week 2 Practice Worksheet

### Intro to the Trig Functions

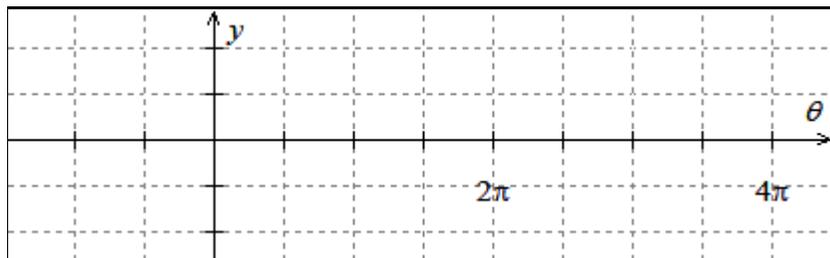
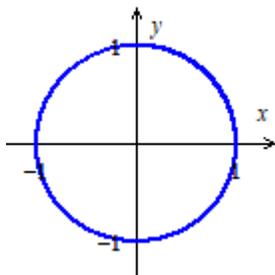
You should complete all of these problems *without a calculator* in order to prepare for the Midterm which is a no-calculator exam.

1. Draw an *accurate* graph of at least two periods of  $y = \cos(\theta)$  and  $y = \sin(\theta)$  on the coordinate planes below. To draw each graph, correctly label at least **two** of the unlabeled “tics” on the  $y$ -axis and all **eight** of the unlabeled “tics” on the  $\theta$ -axis (two tics on the  $\theta$ -axis have been labeled for you); then **plot a point** on your graph that corresponds to **each of the eight tics** that you've labeled on the  $\theta$ -axis and the two pre-labeled tics, and then connect the points to create your graph.



Draw a graph of  $y = \cos(\theta)$ .

Label *all* axis “tics” and plot *all* key points.



Draw a graph of  $y = \sin(\theta)$ .

Label *all* axis “tics” and plot *all* key points.

2. If  $\frac{3\pi}{2} < \theta < 2\pi$  and  $\cos(\theta) = \frac{\sqrt{5}}{4}$ , find the following. Be sure to use proper notation to communicate your answer, i.e., link the given expression and your answer with an equal sign. For example, your response to part (a) should have the form  $\sin(\theta) = \underline{\hspace{2cm}}$  since you're asked to tell me what  $\sin(\theta)$  equals.)

a.  $\sin(\theta)$

b.  $\tan(\theta)$

c.  $\sec(\theta)$

d.  $\csc(\theta)$

3. If  $\frac{\pi}{2} < \theta < \pi$  and  $\sin(\theta) = \frac{6}{7}$ , find the following. Be sure to use proper notation to communicate your answer, i.e., link the given expression and your answer with an equal sign. For example, your response to part (a) should have the form  $\cos(\theta) = \underline{\hspace{1cm}}$  since you're asked to tell me what  $\cos(\theta)$  equals.)

a.  $\cos(\theta)$

b.  $\tan(\theta)$

c.  $\sec(\theta)$

d.  $\csc(\theta)$

4. If  $\frac{\pi}{2} < \theta < \pi$  and  $\csc(\theta) = 3$ , find the following. Be sure to use proper notation to communicate your answer, i.e., link the given expression and your answer with an equal sign. For example, your response to part (a) should have the form  $\sin(\theta) = \underline{\hspace{2cm}}$  since you're asked to tell me what  $\sin(\theta)$  equals.)

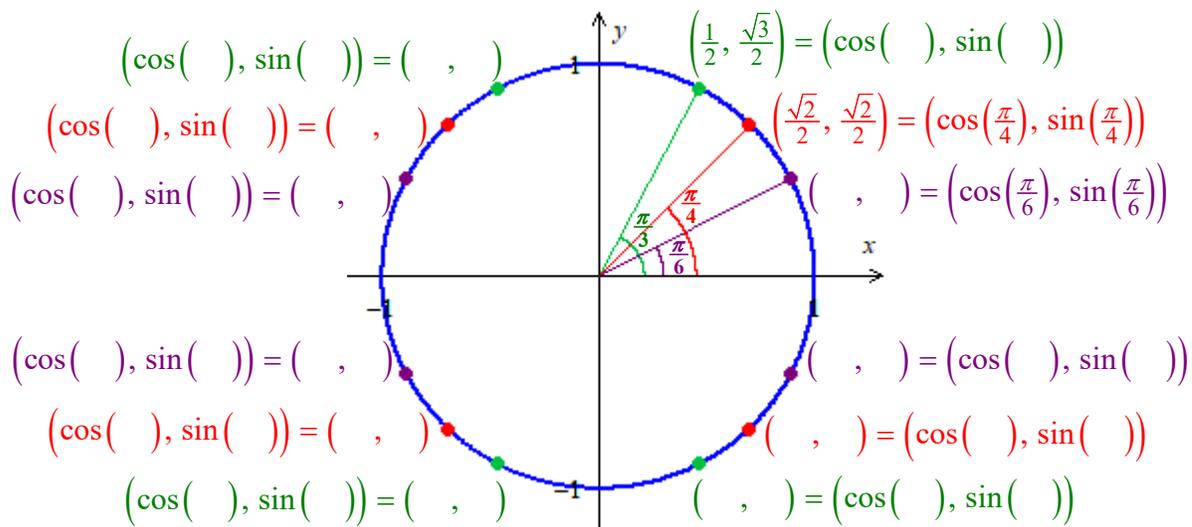
a.  $\sin(\theta)$

b.  $\cos(\theta)$

c.  $\tan(\theta)$

d.  $\sec(\theta)$

5. Label the **coordinates** of each of the 12 dots (three in each of the four quadrants) on the unit circle below. Fill-in the input for the sine and cosine functions in order to indicate the **angle** that specifies each point. Some of the information for the points in Quad 1 has been filled-in.



6. Find  $\sin(\theta)$ ,  $\tan(\theta)$ ,  $\cot(\theta)$ ,  $\sec(\theta)$ , and  $\csc(\theta)$  if:

a.  $\theta = \frac{\pi}{3}$

b.  $\theta = \frac{\pi}{4}$

7. Find  $\sin(\theta)$ ,  $\tan(\theta)$ ,  $\cot(\theta)$ ,  $\sec(\theta)$ , and  $\csc(\theta)$  if:

a.  $\theta = 150^\circ$

b.  $\theta = -\frac{3\pi}{4}$

c.  $\theta = \frac{4\pi}{3}$

8. Find the **exact** value for each of the following expressions. Be sure to use proper notation to communicate your answer, i.e., link the given expression and your answer with an equal sign. If the given expression is undefined write, "*The expression is undefined.*" An example has been provided to clarify how your response should look.

ex.  $\sin(0)$

$$\sin(0) = 0$$


(Write all of this to communicate what " $\sin(0)$ " equals.)

a.  $\cos\left(\frac{\pi}{6}\right).$

b.  $\sin\left(\frac{\pi}{4}\right).$

c.  $\cos(60^\circ).$

d.  $\sin\left(-\frac{5\pi}{3}\right).$

e.  $\sin\left(\frac{17\pi}{6}\right).$

f.  $\cos\left(\frac{7\pi}{6}\right).$

g.  $\sin(240^\circ).$

h.  $\cos(135^\circ).$

i.  $\sec(2\pi).$

j.  $\tan\left(\frac{4\pi}{3}\right).$

9. Find the **exact** value for each of the following expressions. Be sure to use proper notation to communicate your answer, i.e., link the given expression and your answer with an equal sign. If the given expression is undefined write, "*The expression is undefined.*" An example has been provided to clarify how your response should look.

ex.  $\sin(0)$

$$\sin(0) = 0$$


(Write all of this to communicate what " $\sin(0)$ " equals.)

a.  $\sin\left(\frac{\pi}{2}\right)$ .

b.  $\cos(180^\circ)$ .

c.  $\cos\left(\frac{5\pi}{6}\right)$ .

d.  $\sin\left(\frac{7\pi}{6}\right)$ .

e.  $\sin(120^\circ)$ .

f.  $\cos\left(\frac{5\pi}{4}\right)$ .

g.  $\cos\left(\frac{5\pi}{3}\right)$ .

h.  $\sin\left(\frac{20\pi}{3}\right)$ .

i.  $\tan(2\pi)$ .

j.  $\csc\left(\frac{11\pi}{6}\right)$ .

10. A circle with a radius of 6 units is given in Figure 1. The point  $Q$  is specified by the angle  $\frac{5\pi}{6}$ . Use the sine and cosine function to find the exact coordinates of point  $Q$ .

[Be sure to **show your use of sine and cosine.**]

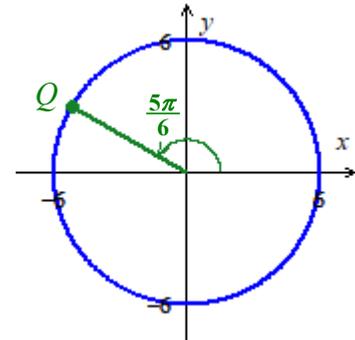


Figure 1

11. The point  $P$  in Figure 2 is specified by  $\frac{7\pi}{4}$  on the circumference of a circle with a radius of 12 units. Use the sine and cosine function to find the **exact** coordinates of  $P$ .

[Be sure to **show your use of sine and cosine.**]

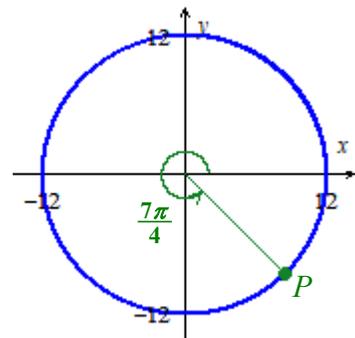


Figure 2

12. The point  $S$  in Figure 3 is specified by  $\frac{4\pi}{3}$  on the circumference of a circle with a radius of 20 units. Use the sine and cosine function to find the **exact** coordinates of  $S$ .

[Be sure to **show your use of sine and cosine.**]

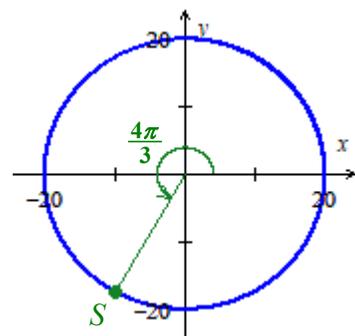


Figure 3

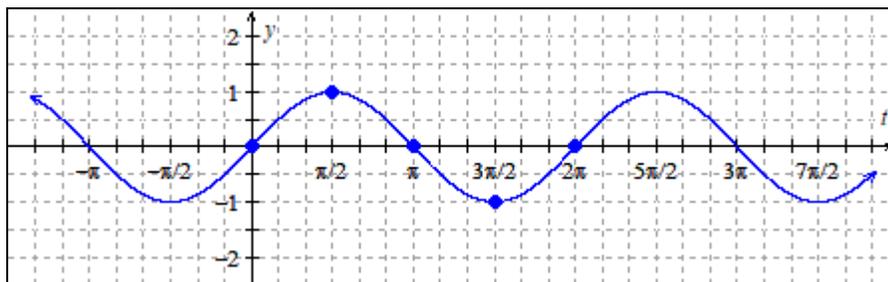


## Week 3 Practice Worksheet

### Graphs of Trig Functions

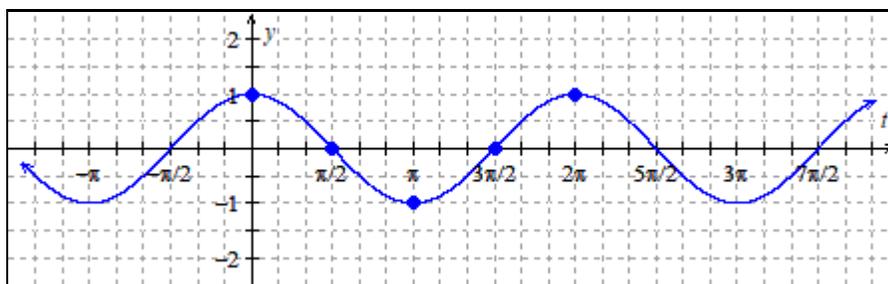
You should complete all of these problems *without a calculator* in order to prepare for the Midterm which is a no-calculator exam.

- The graph of  $y = \sin(t)$  is given below with **five key points** emphasized. As we know, the graph of  $y = \sin\left(t - \frac{2\pi}{3}\right)$  is a *transformation* of  $y = \sin(t)$ . Use what we know about graph transformations to “transform” the **five key points** on  $y = \sin(t)$  and then connect these points in order to construct a graph of  $y = \sin\left(t - \frac{2\pi}{3}\right)$ .



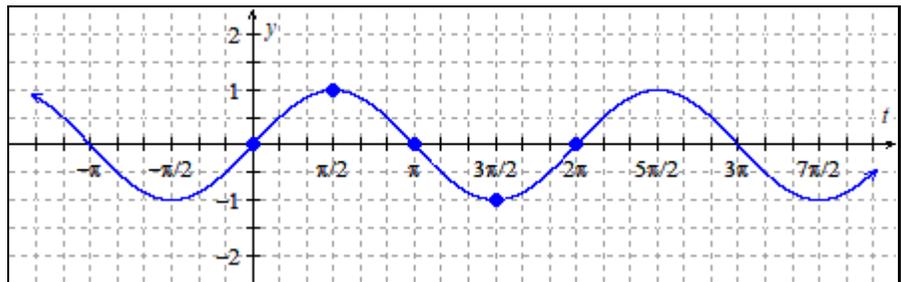
The graph of  $y = \sin(t)$  is given; draw a graph of  $y = \sin\left(t - \frac{2\pi}{3}\right)$ .

- The graph of  $y = \cos(t)$  is given below with **five key points** emphasized. As we know, the graph of  $y = \cos\left(t + \frac{5\pi}{6}\right)$  is a *transformation* of  $y = \cos(t)$ . Use what we know about graph transformations to “transform” the **five key points** on  $y = \cos(t)$  and then connect these points in order to construct a graph of  $y = \cos\left(t + \frac{5\pi}{6}\right)$ .



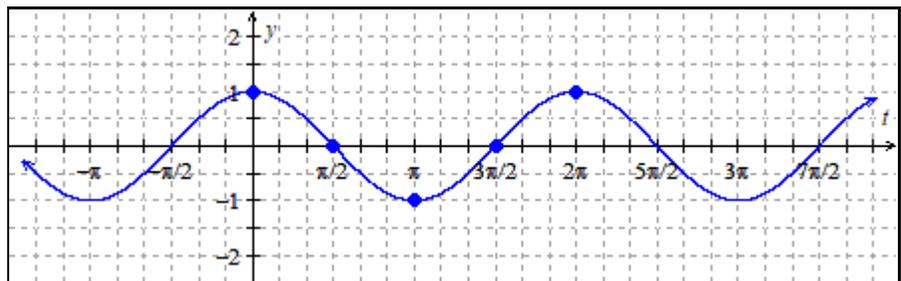
The graph of  $y = \cos(t)$  is given; draw a graph of  $y = \cos\left(t + \frac{5\pi}{6}\right)$ .

3. The graph of  $y = \sin(t)$  is given below with **five key points** emphasized. As we know, the graph of  $y = \sin(t) - 1$  is a *transformation* of  $y = \sin(t)$ . Use what we know about graph transformations to “transform” the **five key points** on  $y = \sin(t)$  and then connect these points in order to construct a graph of  $y = \sin(t) - 1$ .



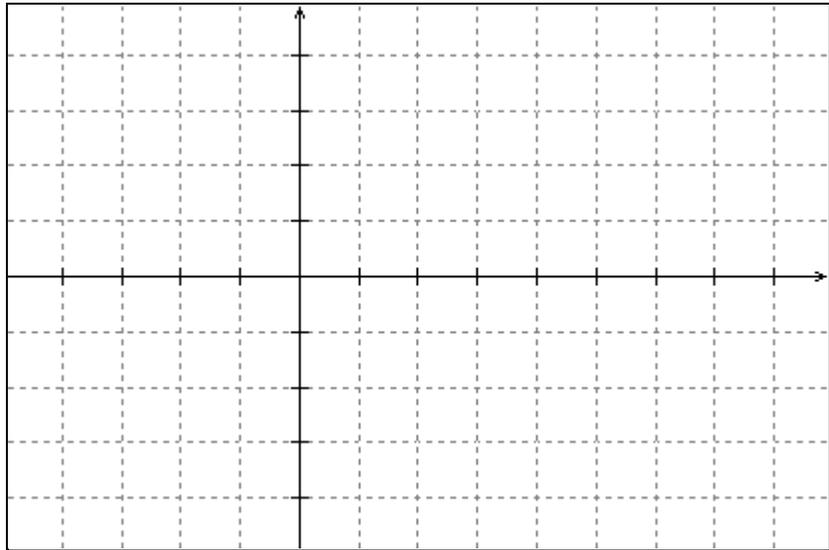
The graph of  $y = \sin(t)$  is given; draw a graph of  $y = \sin(t) - 1$ .

4. The graph of  $y = \cos(t)$  is given below with **five key points** emphasized. As we know, the graph of  $y = 2\cos(t)$  is a *transformation* of  $y = \cos(t)$ . Use what we know about graph transformations to “transform” the **five key points** on  $y = \cos(t)$  and then connect these points in order to construct a graph of  $y = 2\cos(t)$ .



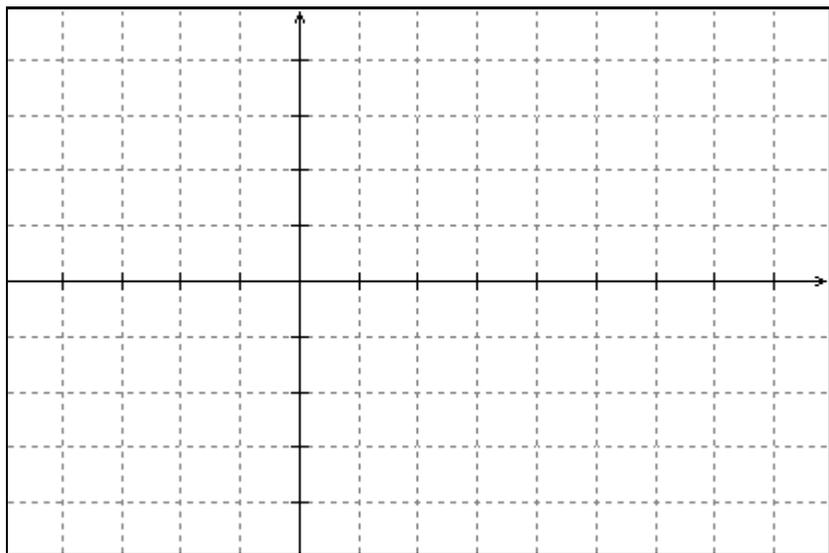
The graph of  $y = \cos(t)$  is given; draw a graph of  $y = 2\cos(t)$ .

5. Scale the axes on the given coordinate plane an appropriately for a graph of  $y = \sin(2t) + 3$  and then draw a graph of  $y = \sin(2t) + 3$  by first plotting the points where the graph will intersect the midline and the points where the graph will reach maximum and minimum values, and then connect these points with an appropriately curved sinusoidal wave.



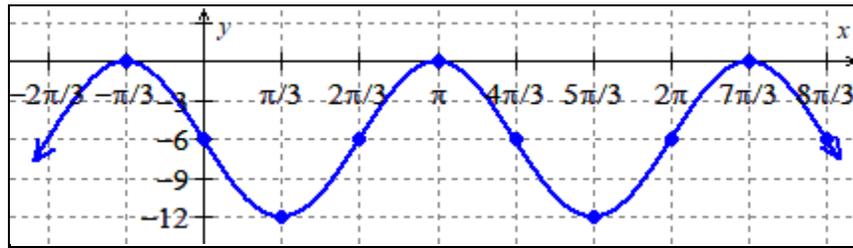
Draw a graph of  $y = \sin(2t) + 3$ .

6. Scale the axes on the given coordinate plane an appropriately for a graph of  $y = 3\cos(\pi t)$  and then draw a graph of  $y = 3\cos(\pi t)$  by first plotting the points where the graph will intersect the midline and the points where the graph will reach maximum and minimum values, and then connect these points with an appropriately curved sinusoidal wave.



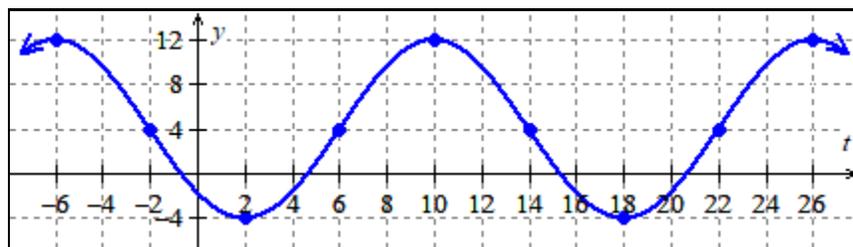
Draw a graph of  $y = 3\cos(\pi t)$ .

7. Find two different algebraic rules for the sinusoidal function  $y = p(x)$  graphed below. One of your rules should involve sine and the other should involve cosine.



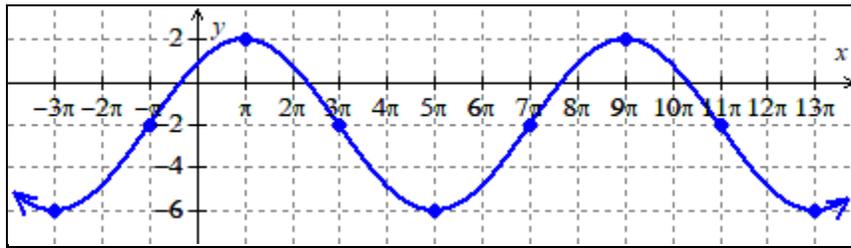
The graph of  $y = p(x)$ .

8. Find two different algebraic rules for the sinusoidal function  $y = q(t)$  graphed below. One of your rules should involve sine and the other should involve cosine.



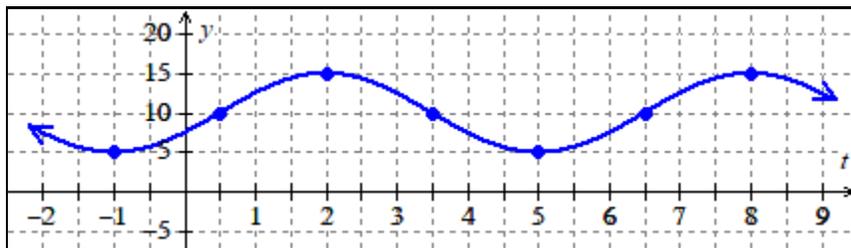
The graph of  $y = q(t)$ .

9. Find two different algebraic rules for the sinusoidal function  $y = m(x)$  graphed below. One of your rules should involve sine and the other should involve cosine.



The graph of  $y = m(x)$ .

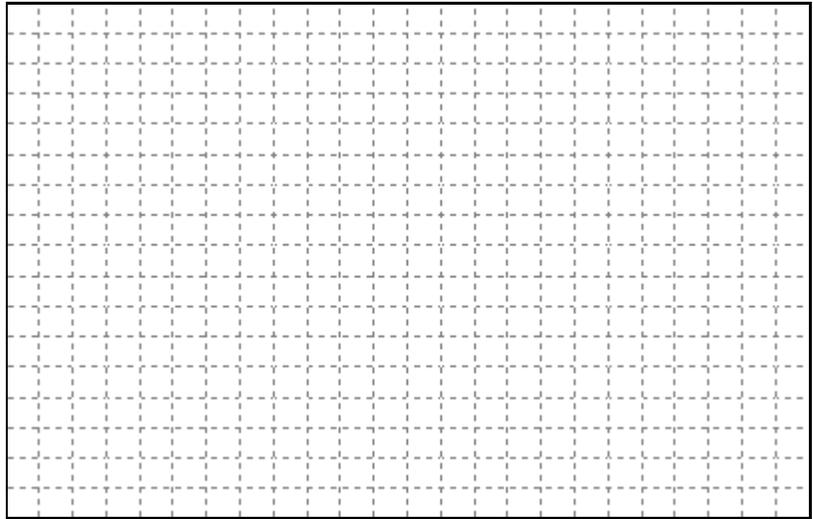
10. Find two different algebraic rules for the sinusoidal function  $y = n(t)$  graphed below. One of your rules should involve sine and the other should involve cosine.



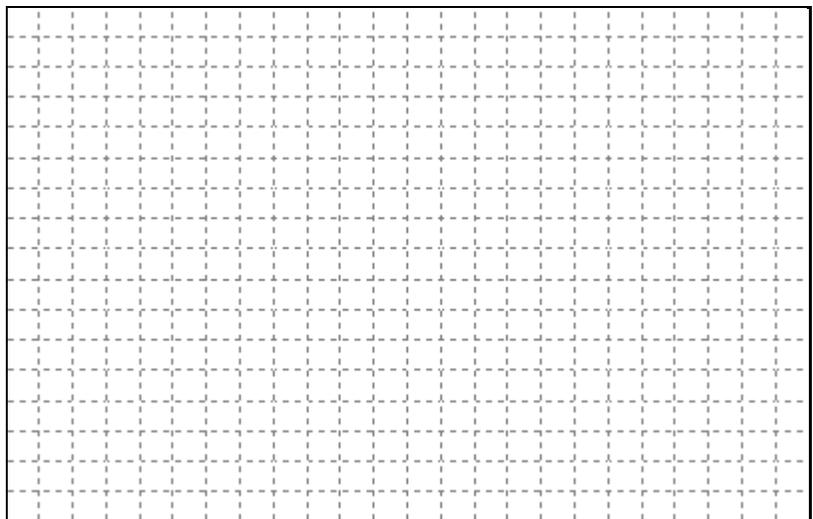
The graph of  $y = n(t)$ .

11. Draw a graph of at least two periods of the functions in **a–f** below by first *plotting the points* where the graph will intersect the midline and *plotting the points* where the graph will reach maximum and minimum values, and then *connect these points* with an appropriately curved sinusoidal wave. List the period, midline, and amplitude of each function. (Be sure to label the scale on the axes of your graph.)

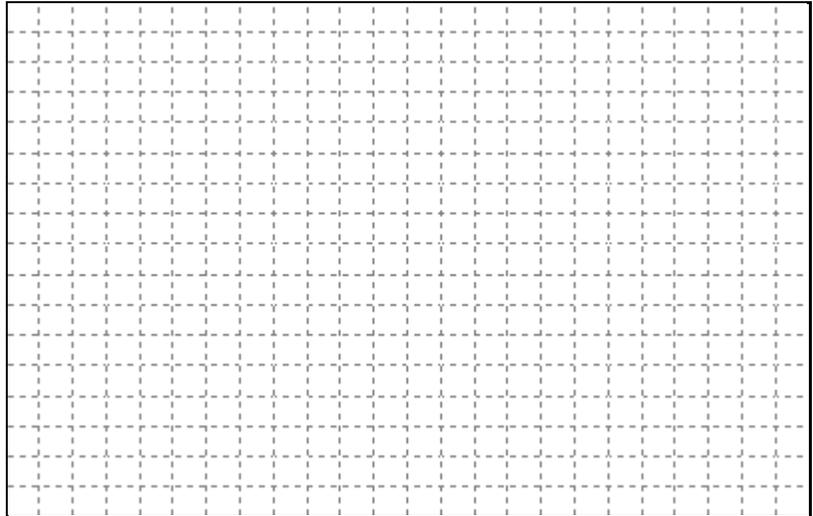
a.  $f(t) = -5 \cos(4t) + 3$



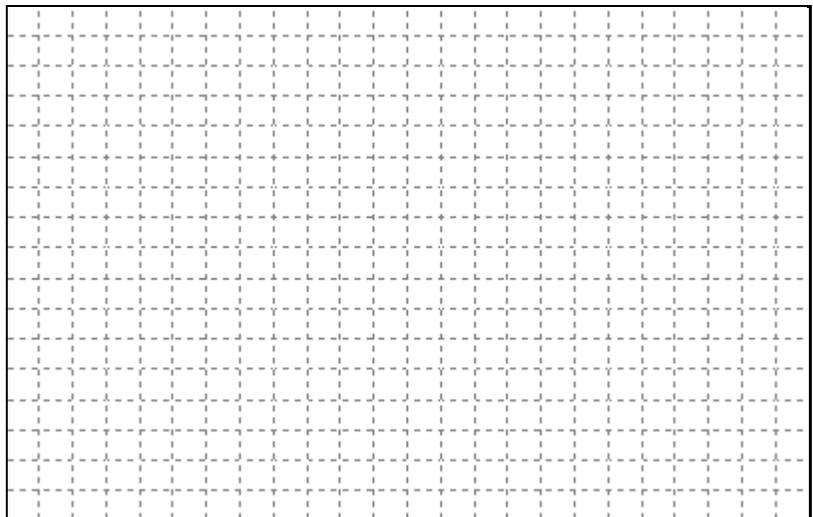
b.  $g(x) = 4 \sin\left(\pi\left(x - \frac{1}{4}\right)\right) - 2$



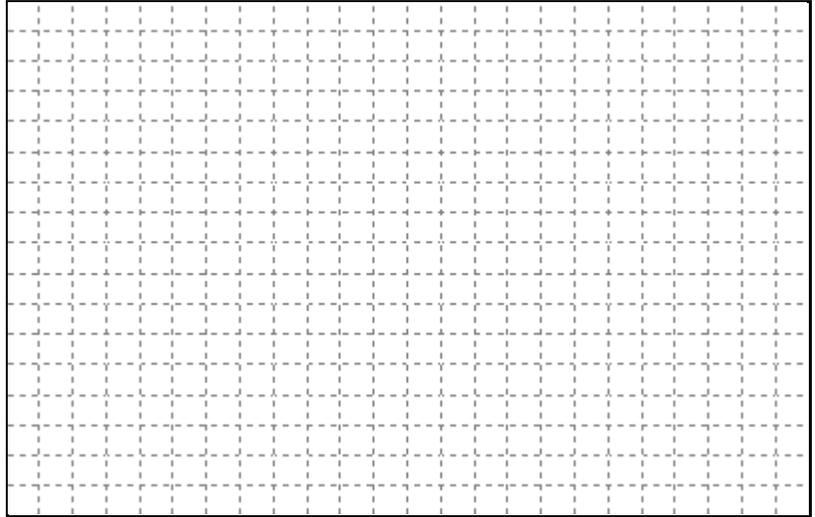
c.  $G(x) = 3 \cos\left(2x + \frac{\pi}{2}\right) + 4$



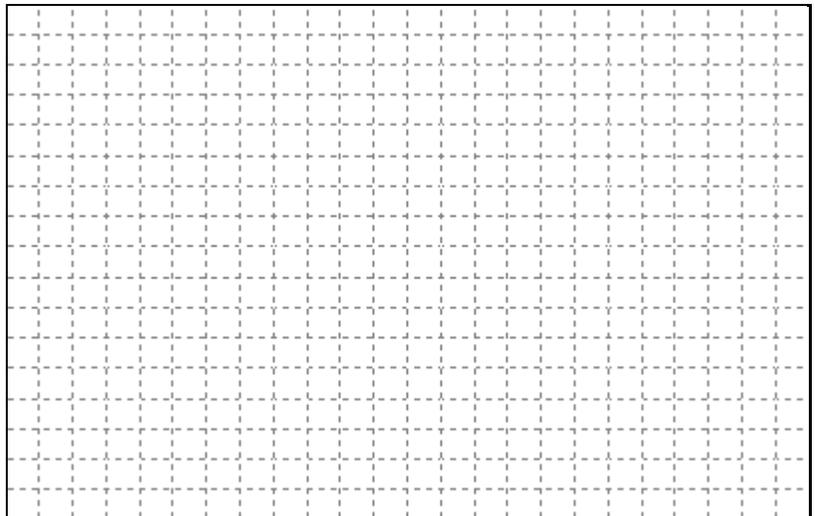
d.  $F(t) = -2 \sin\left(\frac{\pi}{3}t + \pi\right) - 1$



e.  $p(x) = 10 \cos\left(\frac{x + 2\pi}{4}\right) - 5$



f.  $q(t) = -4 \sin\left(\frac{\pi}{4}t - \frac{\pi}{4}\right) - 2$



**12.** Determine the domain of  $y = \tan(t)$ .

**13.** Determine the domain of  $y = \sec(t)$ .

**14.** Determine the domain of  $y = \cot(t)$ .

**15.** Determine the domain of  $y = \csc(t)$ .



## Week 4 Practice Worksheet

### Inverse Trig Functions and Solving Trig Equations

You should complete all of these problems *without a calculator* in order to prepare for the Midterm which is a no-calculator exam.

1. Find the exact value of each of the following expressions; do not use a calculator. Be sure to use proper notation to **directly communicate** what the given expressions equal.

a.  $\sin^{-1}\left(\frac{\sqrt{3}}{2}\right)$

b.  $\cos^{-1}\left(\frac{\sqrt{2}}{2}\right)$

c.  $\sin^{-1}\left(-\frac{1}{2}\right)$

d.  $\cos^{-1}(0)$

e.  $\tan^{-1}(-\sqrt{3})$

f.  $\tan^{-1}(-1)$

2. Find the exact value of each of the following expressions; do not use a calculator. Be sure to use proper notation to **directly communicate** what the given expressions equal.

a.  $\sin\left(\sin^{-1}\left(\frac{\sqrt{3}}{2}\right)\right)$

b.  $\cos\left(\cos^{-1}\left(-\frac{\sqrt{2}}{2}\right)\right)$

c.  $\cos^{-1}\left(\cos\left(\frac{5\pi}{3}\right)\right)$

d.  $\sin^{-1}\left(\sin\left(\frac{4\pi}{3}\right)\right)$

e.  $\sin\left(\cos^{-1}\left(-\frac{\sqrt{3}}{2}\right)\right)$

3. Find the exact value of each of the following expressions; do not use a calculator. Be sure to use proper notation to **directly communicate** what the given expressions equal.

a.  $\sin^{-1}\left(\cos\left(-\frac{\pi}{6}\right)\right)$

b.  $\tan^{-1}\left(\tan\left(\frac{2\pi}{3}\right)\right)$

c.  $\cos^{-1}\left(\tan\left(\frac{3\pi}{4}\right)\right)$

d.  $\tan^{-1}\left(\sin\left(\frac{\pi}{2}\right)\right)$

e.  $\sin\left(\tan^{-1}\left(\frac{1}{\sqrt{3}}\right)\right)$

4. Find the exact value of each of the following expressions; do not use a calculator. Be sure to use proper notation to **directly communicate** what the given expressions equal.

a.  $\sin^{-1}\left(\sin\left(\frac{7\pi}{8}\right)\right)$

b.  $\cos^{-1}\left(\cos\left(\frac{8\pi}{5}\right)\right)$

c.  $\sin^{-1}\left(\sin\left(\frac{9\pi}{7}\right)\right)$

5. Find *all* of the solutions to the equations below; provide *exact* solutions.

a.  $\sin(t) = -\frac{\sqrt{2}}{2}$

b.  $2 \cos(x) - \sqrt{3} = 0$

6. Find the solutions on the interval  $[0, 2\pi)$  for the equations below; provide *exact* solutions.

a.  $\cos(t) = -\frac{1}{2}$

b.  $\frac{\sin(x)}{2} - \frac{\sqrt{3}}{4} = 0$

7. Find *all* of the solutions to the equations below; provide *exact* solutions.

a.  $\sin(6t) = -\frac{\sqrt{3}}{2}$

b.  $5 + 4\cos(2\theta) = 1$

**c.**  $16 \cos(4x) + 11 = 3$

**d.**  $16 - 24 \sin(4t) = 4$

8. Find the solutions on the interval  $[0, 2\pi)$  to following equations.

a.  $5 + 4\cos(2\theta) = 1$

b.  $4 - 6\sin(2x) = 7$

c.  $6\sqrt{2}\cos(3\alpha) + 10 = 4$



## Week 5 Practice Worksheet

### Some Additional Practice for the Midterm Exam

This isn't meant to be a "practice test" or "the only thing you need to study to be prepared for the exam." It's just some additional practice problems. If you're comfortable with all of these problems, then you should be prepared for the exam but, in addition to the problems below, you should also study the ClassNotes/Videos, the Online Lecture Notes, the Weekly Practice Worksheets, the Weekly Graded Worksheets, and the suggested practice problems from the online textbook.

**You should NOT use a calculator for ANY of the problems below since you won't be allowed to use a calculator on the Midterm.**

- Convert  $24^\circ$  into radians.
  - Convert  $\frac{3}{2}$  radians into degrees.
  
- Find the arc-length spanned by an angle measuring  $75^\circ$  on a circle of radius 30 feet.

3. Evaluate the following expressions:

a.  $\sin\left(\frac{\pi}{3}\right)$ .

b.  $\cos(45^\circ)$ .

c.  $\sin(330^\circ)$ .

d.  $\cos\left(\frac{\pi}{2}\right)$ .

e.  $\cos\left(\frac{2\pi}{3}\right)$ .

f.  $\sin\left(\frac{5\pi}{4}\right)$ .

g.  $\sin\left(\frac{7\pi}{6}\right)$ .

h.  $\cos\left(\frac{11\pi}{6}\right)$ .

i.  $\cos\left(\frac{17\pi}{6}\right)$ .

k.  $\sin\left(\frac{16\pi}{3}\right)$ .

l.  $\tan\left(\frac{3\pi}{4}\right)$ .

m.  $\cot\left(\frac{4\pi}{3}\right)$ .

n.  $\csc(\pi)$ .

o.  $\sec(360^\circ)$ .

4. a. Use the sine and cosine functions to find the coordinates of the point  $P$  in Figure 1a that is specified by  $\frac{5\pi}{3}$  on the circumference of a circle of radius 10 units. **Clearly show your use of the sine and cosine functions.**

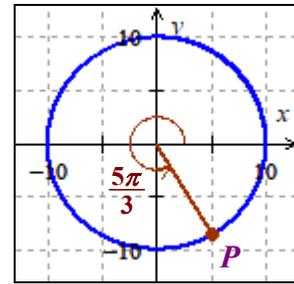


Figure 1a

- b. Use the sine and cosine functions to find the coordinates of the point  $Q$  in Figure 1b that is specified by  $\frac{7\pi}{6}$  on the circumference of a circle of radius 3 units. **Clearly show your use of the sine and cosine functions.**

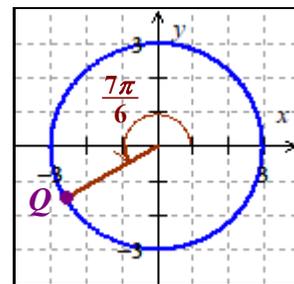


Figure 1b

5. If  $\sin(\theta) = \frac{3}{4}$  and  $\frac{\pi}{2} < \theta < \pi$ , find the exact value of the following:

a.  $\cos(\theta)$

b.  $\sin(\theta + 2\pi)$

c.  $\tan(\theta)$

d.  $\sec(\theta)$

e.  $\csc(\theta)$

6. Find *all* of the solutions to the following equations:

a.  $3\sin(x) + 4 = 5$

b.  $2\cos(\theta) = 1$

**c.**  $2 \sin(3\theta) + \sqrt{3} = 0$

**d.**  $7 + 3\sqrt{2} \cos(4t) = 4$

7. Find all of the solutions to the following equations on the interval  $[0, 2\pi)$ .

a.  $6\cos(2x) + 5 = 2$

b.  $2 - 3\sin(4\theta) = 5$

8. Evaluate the following. Show your steps. (Do not use a calculator!)

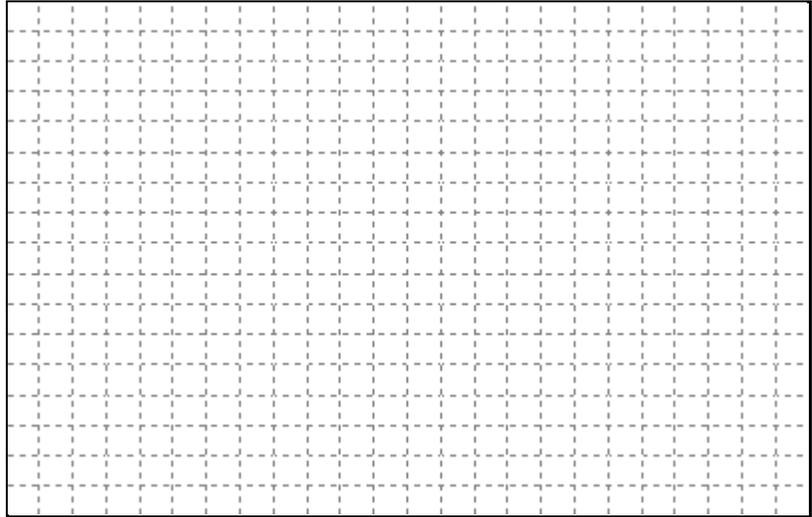
a.  $\sin\left(\cos^{-1}\left(-\frac{1}{2}\right)\right)$

b.  $\sin^{-1}\left(\sin\left(\frac{7\pi}{4}\right)\right)$

c.  $\cos^{-1}\left(\sin\left(\frac{4\pi}{3}\right)\right)$

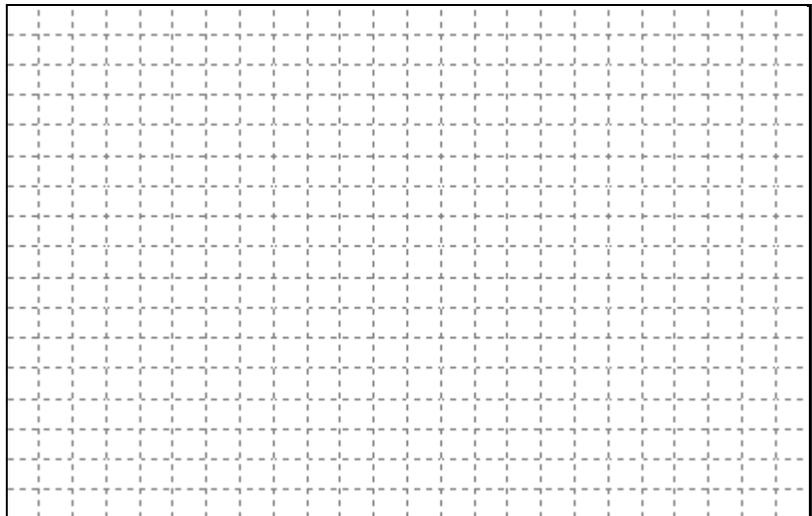
d.  $\cos^{-1}\left(\cos\left(\frac{8\pi}{7}\right)\right)$

9. Sketch a graph of the function  $g(t) = 3\sin\left(2t + \frac{\pi}{4}\right) - 2$ . State the period, midline, and amplitude of  $g$ .



Draw a graph of  $y = g(t)$ .

10. Sketch a graph of the function  $q(x) = 2\cos\left(\frac{\pi}{2}x + \frac{\pi}{4}\right) - 3$ . State the period, midline, and amplitude of  $q$ .



Draw a graph of  $y = q(x)$ .

11. Find four algebraic rules (one using “positive sine”, one using “negative (reflected) sine”, one using “positive cosine”, and one using “negative (reflected) cosine”) for the function  $y = p(x)$  graphed in Figure 2.

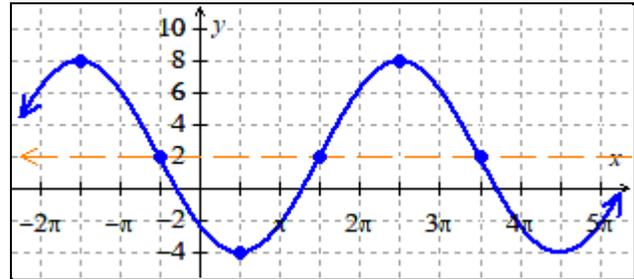


Figure 2: A graph of  $y = p(x)$ .

12. a. Find four algebraic rules (one using “positive sine”, one using “negative (reflected) sine”, one using “positive cosine”, and one using “negative (reflected) cosine”) for the function  $y = f(t)$  graphed in Figure 3.

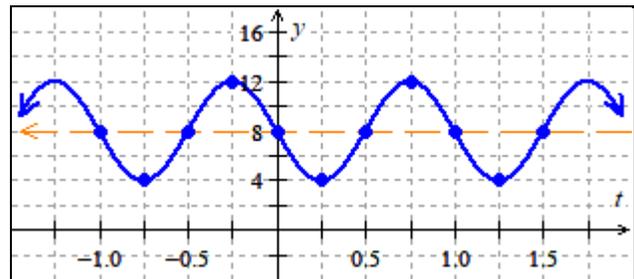


Figure 3: A graph of  $y = f(t)$ .

- b. Use one of your answers to part a to find exact solutions to  $f(t) = 10$ .

## Week 6 Practice Worksheet

### Right Triangles and Non-right Triangles

1. a. Find the exact value of all six trig functions for the angles  $A$  and  $B$  in the triangle in Figure 1. (The triangle may not be drawn to scale.)

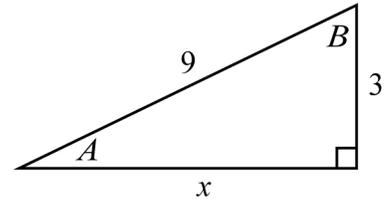
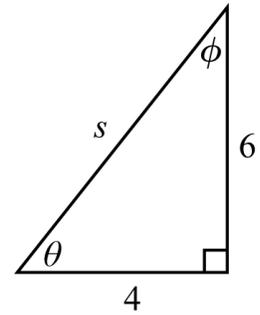


Figure 1

- b. Solve the triangle in Figure 1 by finding approximate measurements (in degrees) of angles  $A$  and  $B$  and the exact length of the side  $x$ .

2. a. Find the exact value of all six trig functions for the angles  $\theta$  and  $\phi$  in the triangle in Figure 2. (The triangle may not be drawn to scale.)



**Figure 2**

- b. Solve the triangle in Figure 2 by finding approximate measurements (in degrees) of angles  $\theta$  and  $\phi$  and the exact length of the side  $s$ .

3. Find the values of  $c$ ,  $A$ , and  $B$  in the triangle in Figure 3. You should approximate the values (in degrees for the angles) and denote your approximations correctly. (The triangle may not be drawn to scale.)

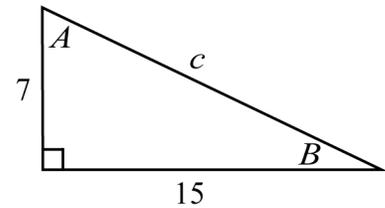


Figure 3

4. Find the values of  $p$ ,  $q$ , and  $\theta$  in the triangle in Figure 4. You should approximate the values (in degrees for the angles) and denote your approximations correctly. (The triangle may not be drawn to scale.)

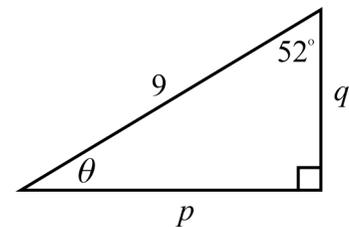
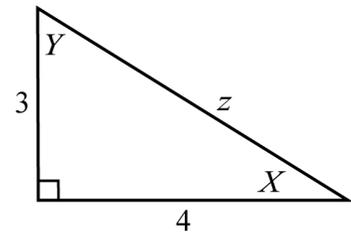


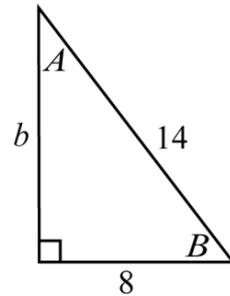
Figure 4

5. Find the values of  $z$ ,  $X$  and  $Y$  in the triangle in Figure 5. You should approximate the values (in degrees for the angles) and denote your approximations correctly. (The triangle may not be drawn to scale.)



**Figure 5**

6. Find the values of  $b$ ,  $A$ , and  $B$  in the triangle in Figure 6. You should approximate the values (in degrees for the angles) and denote your approximations correctly. (The triangle may not be drawn to scale.)



**Figure 6**

7. In parts (a) – (i), you are given some info about a non-right triangle that has sides  $a$ ,  $b$ , and  $c$  and angles  $A$ ,  $B$ , and  $C$  oriented as shown in Figure 7. Find the length of the missing side(s) and the measure of the missing angle(s). (You'll need to use the Laws of Sines and Cosines which are included on the [Identities and Formulas Reference Sheet](#) that will be provided to you during the Final Exam so you don't need to memorize them.) You should approximate the values (in degrees for the angles) and denote your approximations correctly. [You'll need your own paper to work these problems.]

a.  $a = 5$ ,  $b = 6$ ,  $c = 7$

b.  $B = 76^\circ$ ,  $a = 8$ ,  $c = 6$

c.  $B = 118^\circ$ ,  $C = 37^\circ$ ,  $a = 5$

d.  $A = 62^\circ$ ,  $B = 70^\circ$ ,  $b = 10$

e.  $A = 64^\circ$ ,  $C = 76^\circ$ ,  $b = 9$

f.  $C = 40^\circ$ ,  $a = 9$ ,  $b = 13$

g.  $A = 40^\circ$ ,  $a = 11$ ,  $c = 8$

h.  $A = 28^\circ$ ,  $a = 7$ ,  $c = 12$  (this is an "ambiguous situation" where there are two possible triangles that satisfy the given information: try to find both of the solutions)

i.  $C = 67^\circ$ ,  $a = 8$ ,  $c = 5$  (this is an "impossible situation" where there is no triangle that satisfies: try to figure out why it is impossible)

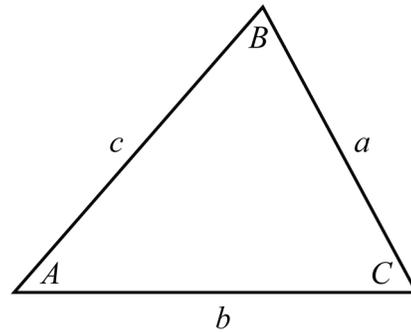


Figure 7

8. As you know, a triangle has three sides and three angles: these are the "six components of a triangle." Notice that in each part of the previous problem (#5) you are given the measurements of **three** of these six components. Sometimes (like in part (a)) you are given the lengths of all three sides; usually you are given a combination of sides and angles; but you aren't ever given all three angle measures: contemplate, discuss, and explain why.



# Week 7 Practice Worksheet

## Trig Identities

1. Prove the following identities. (Be sure to organize your proof as shown in the Online Lecture Notes and class notes videos.) This means that you should start your proof by writing one side of the identity and then use equal signs between equivalent expressions until you obtain the other side of the identity. You should only include one step on each line and you should align your equal signs on the left of each step. Compare your proofs with those given in the solutions to make sure that you are using the correct organization and technique.)

a.  $\tan(x)\sec(x) = \sin(x)\sec^2(x)$

b.  $\csc(t) - \sin(t) = \cot(t)\cos(t)$

**c.**  $\frac{\sec(\theta)}{\sin(\theta)} - \tan(\theta) = \cot(\theta)$

**d.**  $\frac{1}{1 - \cos(x)} - \frac{1}{1 + \cos(x)} = 2 \cot(x) \csc(x)$

**e.**  $\sec(\theta) + \tan(\theta) = \frac{\cos(\theta)}{1 - \sin(\theta)}$

**f.**  $\cot(A) = \csc(A)\sec(A) - \tan(A)$

2. Use a **sum-of-angles** or **difference-of-angles identity** to calculate the *exact value* of each of the following. (These identities are included on the [Identities and Formulas Reference Sheet](#) that will be provided to you during the Final Exam.)

a.  $\sin(165^\circ)$

b.  $\cos\left(\frac{13\pi}{12}\right)$

c.  $\tan\left(\frac{17\pi}{12}\right)$

3. In order to get familiar with the **sum-of-angles**, **difference-of-angles**, **double-angle** and **half-angle identities**, we'll use these identities to calculate some "friendly" sine and cosine values – so we already know these sine and cosine values and we'll verify that the identities lead us to these values. To help explain the activity part (a) has been worked out for you, and part (b) has been started. (These identities are included on the [Identities and Formulas Reference Sheet](#) that will be provided to you during the Final Exam.)

- a. Find  $\sin\left(\frac{\pi}{2}\right)$  using the fact that  $\frac{\pi}{2} = \frac{\pi}{6} + \frac{\pi}{3}$ .

$$\begin{aligned}\sin\left(\frac{\pi}{2}\right) &= \sin\left(\frac{\pi}{6} + \frac{\pi}{3}\right) \\ &= \sin\left(\frac{\pi}{6}\right)\cos\left(\frac{\pi}{3}\right) + \cos\left(\frac{\pi}{6}\right)\sin\left(\frac{\pi}{3}\right) \\ &= \frac{1}{2} \cdot \frac{1}{2} + \frac{\sqrt{3}}{2} \cdot \frac{\sqrt{3}}{2} \\ &= \frac{1}{4} + \frac{3}{4} \\ &= 1\end{aligned}$$

We know that  $\sin\left(\frac{\pi}{2}\right) = 1$  so the identity gave us the correct value.

- b. Find  $\cos\left(\frac{\pi}{2}\right)$  using the fact that  $\frac{\pi}{2} = \frac{\pi}{4} + \frac{\pi}{4}$ .

- c. Find  $\sin\left(\frac{2\pi}{3}\right)$  using the fact that  $\frac{2\pi}{3} = 2 \cdot \frac{\pi}{3}$ . (hint: use a double-angle identity)

d. Find  $\cos\left(\frac{\pi}{3}\right)$  using the fact that  $\frac{\pi}{3} = 2 \cdot \frac{\pi}{6}$ . (hint: use a double-angle identity)

e. Find  $\sin\left(\frac{\pi}{4}\right)$  using the fact that  $\frac{\pi}{4} = \frac{\pi/2}{2}$ . (Hint: use a half-angle identity)

f. Find  $\cos(30^\circ)$  using the fact that  $30^\circ = \frac{60^\circ}{2}$ . (hint: use a half-angle identity)

4. Suppose that  $\sin(\alpha) = -\frac{\sqrt{65}}{9}$  and  $\pi < \alpha < \frac{3\pi}{2}$ . Calculate the *exact value* of each of the following using an appropriate **double-angle** or **half-angle identity**. (These identities are included on the [Identities and Formulas Reference Sheet](#).)
- a.  $\sin(2\alpha)$ . [Hint: first find  $\cos(\alpha)$ ]

---

b.  $\cos(2\alpha)$ .

c.  $\sin\left(\frac{\alpha}{2}\right)$ .

5. Suppose that  $\cos(\theta) = \frac{7}{10}$  and  $\frac{3\pi}{2} < \theta < 2\pi$ . Calculate the *exact value* of each of the following using an appropriate **double-angle** or **half-angle identity**. (These identities are included on the [Identities and Formulas Reference Sheet](#).)

a.  $\sin(2\theta)$ . [Hint: first find  $\sin(\theta)$ ]

---

b.  $\cos(2\theta)$ .

c.  $\cos\left(\frac{\theta}{2}\right)$ .

6. Suppose that  $\sin(x) = \frac{9}{11}$  and  $\frac{\pi}{2} < x < \pi$ . Calculate the *exact value* of each of the following using an appropriate **double-angle** or **half-angle identity**. (These identities are included on the [Identities and Formulas Reference Sheet](#).)

a.  $\sin(2x)$ . [Hint: first find  $\cos(x)$ ]

---

b.  $\cos(2x)$ .

c.  $\sin\left(\frac{x}{2}\right)$ .

7. Prove the following identities using the double-angle identities for sine and cosine included on the [Identities and Formulas Reference Sheet](#). (Be sure to organize your proof as shown in the Online Lecture Notes and class notes videos.)

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

(this is known as the double-angle identity for tangent; to prove it, start with the left side and use the double-angle identities for sine and cosine; for cosine, use  $\cos(2x) = \cos^2(x) - \sin^2(x)$ ; a “trick” here is to introduce a term that will create the denominator that you need)

b.  $\frac{1 - \cos(2t)}{\sin(2t)} = \tan(t)$

## Week 8 Practice Worksheet

### Polar Coordinates

1. Translate each of the following rectangular coordinates  $(x, y)$  into polar coordinates  $(r, \theta)$ . Your answers should be ordered pairs involving exact values, with  $\theta$  in radians.

a.  $(x, y) = (-4, -4)$

b.  $(x, y) = (6, -6\sqrt{3})$

2. Translate each of the following rectangular coordinates  $(x, y)$  into polar coordinates  $(r, \theta)$ . Your answers should be ordered pairs involving approximations of  $\theta$  in radians.

a.  $(x, y) = (10, -2)$

b.  $(x, y) = (-3, 7)$

3. Translate each of the following polar coordinates  $(r, \theta)$  into rectangular coordinates  $(x, y)$ . Your answers should be ordered pairs involving exact values.

a.  $(r, \theta) = \left(5, \frac{2\pi}{3}\right)$

b.  $(r, \theta) = (16, 210^\circ)$

4. Translate each of the following polar coordinates  $(r, \theta)$  into rectangular coordinates  $(x, y)$ . Your answers should be ordered pairs involving approximate values.

a.  $(r, \theta) = (3, 80^\circ)$

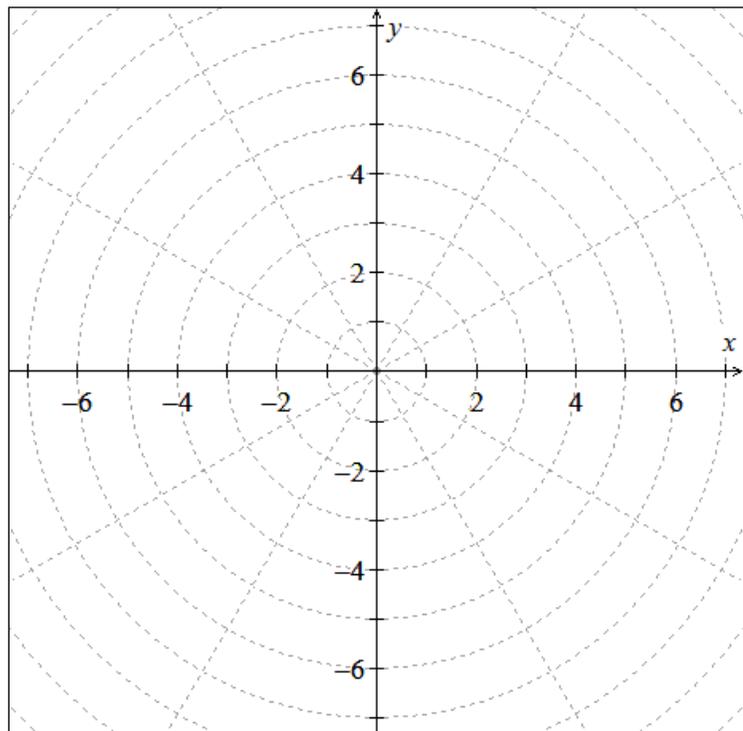
b.  $(r, \theta) = \left(7, -\frac{\pi}{10}\right)$

5. The polar ordered pair  $(5, \frac{\pi}{3})$  can be plotted as a “dot” on the polar coordinate plane. List four other (different) polar ordered pairs that are plotted on the same “dot.” Use “ $r = -5$ ” for at least one of your ordered pairs.

6. Complete the 1<sup>st</sup> column of the table below with appropriate multiples of  $\frac{\pi}{6}$ ,  $\frac{\pi}{4}$ , and  $\frac{\pi}{3}$ ; then determine the corresponding values of  $r$  if  $r = 6 \cos(2\theta)$  in order to complete the 2<sup>nd</sup> column of the table; then plot the points implied by each of the 16 rows of the table on the polar plane below and connect those points in order to draw a graph of  $r = 6 \cos(2\theta)$ .

(HINT: Graph the function in Desmos so that you can predict its shape before you draw it.)

	$\theta$	$r$
	0	
Quad. 1 angles		
	$\frac{\pi}{2}$	
Quad. 2 angles		
	$\pi$	
Quad. 3 angles		
	$\frac{3\pi}{2}$	
Quad. 4 angles		



Draw a graph of  $r = 6 \cos(2\theta)$ .

7. Express the complex number  $z = 10e^{i\frac{11\pi}{6}}$  in the form  $z = a + bi$ .

8. Express the complex number  $z = 8e^{i\frac{2\pi}{3}}$  in the form  $z = a + bi$ .

9. Express the complex number  $z = -7e^{i\frac{5\pi}{4}}$  in the form  $z = a + bi$ .

10. Find a polar form,  $z = re^{i\theta}$ , of the complex number  $z = -3 - 3\sqrt{3}i$ .

11. Find a polar form,  $z = re^{i\theta}$ , of the complex number  $z = 2 - 2i$ .

12. Find a polar form,  $z = re^{i\theta}$ , of the complex number  $z = -4\sqrt{3} + 12i$ .

13. Find three different polar forms,  $z = re^{i\theta}$ , of the complex number  $z = 4i$ . (HINT:  $i = 0 + 4i$  can be associated with the point  $(0, 4)$  so find three different angles that can be used to represent the "direction of this point" and use each angle to create a polar form.)

## Week \_\_ Practice Worksheet

### Vectors

1. Suppose that  $\vec{v} = \langle -3, 7 \rangle$  and  $\vec{w} = \langle 2, 10 \rangle$ .

a. Express  $\vec{v}$  and  $\vec{w}$  using unit vectors.

b. Find  $\|\vec{v}\|$  and  $\|\vec{w}\|$ .

c. Find  $2\vec{v} - 5\vec{w}$ .

d. Find  $4\vec{w} + 3\vec{v}$ .

2. Suppose that  $\vec{m} = 7\vec{i} - 4\vec{j}$  and  $\vec{n} = -5\vec{i} - 2\vec{j}$ .
- Express  $\vec{m}$  and  $\vec{n}$  using “pointy vector brackets” (i.e.,  $\langle a, b \rangle$ ).
  - Find  $\|\vec{m}\|$  and  $\|\vec{n}\|$ .
  - Find  $\vec{m} + \vec{n}$ .
  - Find  $3\vec{m} - \vec{n}$ .

3. Suppose that  $\vec{p} = \langle -1, 4 \rangle$  and  $\vec{q} = \langle 3, -5 \rangle$ .

a. Express  $\vec{p}$  and  $\vec{q}$  using unit vectors.

b. Find  $\|\vec{p}\|$  and  $\|\vec{q}\|$ .

c. Find  $2\vec{p} + 3\vec{q}$ .

d. Find  $2\vec{q} - 3\vec{p}$ .

4. Suppose that the tail (or initial point) of  $\vec{b}$  is  $(2, -3)$  and the tip (or terminal point) is  $(-4, 7)$ . Find the components of  $\vec{b}$  in order to express  $\vec{b}$  using both “pointy vector brackets” and unit vectors.
  
5. Suppose that the tail (or initial point) of  $\vec{r}$  is  $(-5, 1)$  and the tip (or terminal point) is  $(3, 6)$ . Find the components of  $\vec{r}$  in order to express  $\vec{r}$  using both “pointy vector brackets” and unit vectors.
  
6. Suppose that  $\|\vec{a}\| = 34$  and that  $\vec{a}$  makes an angle of  $150^\circ$  with the positive  $x$ -axis. Find the components of  $\vec{a}$  in order to express  $\vec{a}$  using both “pointy vector brackets” and unit vectors.
  
7. Suppose that  $\|\vec{s}\| = 18$  and that  $\vec{s}$  makes an angle of  $-45^\circ$  with the positive  $x$ -axis. Find the components of  $\vec{s}$  in order to express  $\vec{s}$  using both “pointy vector brackets” and unit vectors.

8. Suppose that  $\vec{v} = \langle -3, 7 \rangle$  and  $\vec{w} = \langle 2, 10 \rangle$ .

a. Find  $\vec{v} \cdot \vec{w}$ .

b. Find the angle between  $\vec{v}$  and  $\vec{w}$ .

9. Suppose that  $\vec{m} = 7\vec{i} - 4\vec{j}$  and  $\vec{n} = -5\vec{i} - 2\vec{j}$ .

a. Find  $\vec{m} \cdot \vec{n}$ .

b. Find the angle between  $\vec{m}$  and  $\vec{n}$ .

10. Suppose that  $\vec{p} = \langle -1, 4 \rangle$  and  $\vec{q} = \langle 3, -5 \rangle$ .

a. Find  $\vec{p} \cdot \vec{q}$ .

b. Find the angle between  $\vec{p}$  and  $\vec{q}$ .



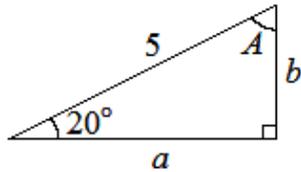
## Week \_\_ Practice Worksheet

### Some Additional Practice for the Final Exam

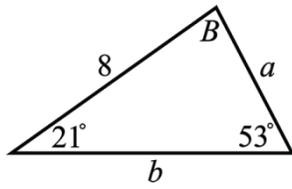
This isn't meant to be a "practice test" or "the only thing you need to study to be prepared for the exam." It's just some additional practice problems covering the material that we studied after the Midterm. In addition to the problems below, you should also study the Class Notes Videos, the Online Lecture Notes, the Weekly Practice Worksheets (especially "Week 5: Practice Worksheet"), the Weekly Graded Worksheets, and the suggested practice problems from the online textbook.

1. Find the missing side(s) and missing angle(s) for the triangles given below. (The triangles may not be drawn to scale.)

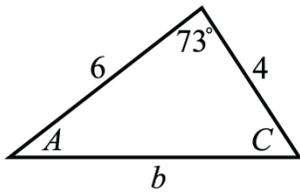
a.



**b.**



**c.**



2. Suppose that  $\sin(\alpha) = \frac{5}{13}$  and  $\cos(\beta) = \frac{3}{5}$ , and where  $0 < \alpha < \frac{\pi}{2}$  and  $\frac{3\pi}{2} < \beta < 2\pi$ . Find the exact value of:

a.  $\sin(\alpha + \beta)$ .

b.  $\cos(\alpha - \beta)$ .

c.  $\sin(2\beta)$ .

d.  $\cos(2\beta)$ .

**e.**  $\sin\left(\frac{\beta}{2}\right).$

**f.**  $\cos\left(\frac{\beta}{2}\right).$

**3.** Prove the following identities.

**a.**  $\tan(x) + \cot(x) = \sec(x)\csc(x)$

**b.**  $\tan^2(x) - \sin^2(x) = \tan^2(x)\sin^2(x)$

**c.**  $\cos(2x) = \cos^4(x) - \sin^4(x)$

4. Convert the following polar ordered pairs into Cartesian (i.e., rectangular) coordinates.

a.  $\left(3, \frac{\pi}{2}\right)$

b.  $\left(\pi, \frac{5\pi}{3}\right)$

c.  $(10, -10^\circ)$

5. Convert the following Cartesian (i.e., rectangular) ordered pairs into polar coordinates.

a.  $(10, -10)$

b.  $(-3, 0)$

c.  $(-8, -8\sqrt{3})$

6. Translate the complex number  $z = -3 + 3\sqrt{3} \cdot i$  into its polar form  $z = re^{i\theta}$ .

7. Translate the polar form of the complex number  $z = 4e^{i \cdot \frac{5\pi}{6}}$  into its rectangular form  $z = a + bi$ .

8. Determine the magnitude and direction (with respect to the positive  $x$ -axis) of the vector  $\vec{v} = \langle -3, -7 \rangle$ .

9. a. Find the horizontal and vertical components of the vector  $\vec{v}$  that starts at the point  $P = (5, 6)$  and ends at the point  $Q = (2, 2)$ .

- b. Find the magnitude,  $\|\vec{v}\|$ , and the direction (with respect to the positive  $x$ -axis) of the vector  $\vec{v}$  that you found in part a?

10. Suppose  $\vec{v} = \langle -4, 1 \rangle$  and  $\vec{u} = \langle 3, -6 \rangle$ .

a. Find  $\vec{w} = \vec{v} - 2\vec{u}$ .

b. Use the *dot product* to find the angle between  $\vec{v} = \langle -4, 1 \rangle$  and  $\vec{u} = \langle 3, -6 \rangle$ ?