

## Making Mathematics Connections through Conic Sections

Richard Parr  
rparr@rice.edu

Rice University School Mathematics Project  
<http://rusmp.rice.edu>



### Conics in Geometry

#### *Activity #1*

Using a compass, draw Circle P on a piece of patty paper. Label a point A other than the center in the interior of the circle. Take a point on the circle and fold the patty paper so that the point lies on top of A. Create the crease. Repeat this process for other points on the circle. What figure is created? Why?

Re-create this construction with technology.

#### *Activity #2*

Next, using a compass, draw Circle Q on a piece of patty paper. Label a point B other than the center on the exterior of the circle. Take a point on the circle and fold the patty paper so that the point lies on top of B. Create the crease. Repeat this process for other points on the circle. What figure is created? Why?

Re-create this construction with technology.

## Parametric Representations of the Conic Sections

The Pythagorean trigonometric identities allow for easy parametric representation of ellipses and hyperbolas. Parabolas are most easily represented without the use of trigonometry.

### *Ellipses*

A comparison of the Pythagorean identity:  $\cos^2 t + \sin^2 t = 1$

and a standard form for the equation of an ellipse :  $\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$

allows for two simple substitutions :  $\cos^2 t = \frac{(x-h)^2}{a^2}$  and  $\sin^2 t = \frac{(y-k)^2}{b^2}$ .

Solving these two equations for x and y yields a pair of parametric equations:

$$\begin{aligned}x &= a \cos t + h \\y &= b \sin t + k\end{aligned}$$

Re-express  $\frac{(x-4)^2}{9} + \frac{(y+1)^2}{4} = 1$  using parametric equations and graph.

A few personal comments are important at this point:

I chose substitutions I did to reinforce the use of  $x$  and  $y$  coordinates of a unit circle to represent sine and cosine respectively. In using this method I am de-emphasizing the idea that “ $a$ ” corresponds to the major axis, etc. I focus on the idea that “ $a$ ” is a stretch in the  $x$  equation and therefore a horizontal stretch. Likewise, “ $b$ ” is a vertical stretch. I’d just as soon not use the letters “ $a$ ” and “ $b$ ” at all, but focus on the major axis being the axis with the “largest” stretch.

### *Hyperbolas*

By using the Pythagorean identity:  $\sec^2 t - \tan^2 t = 1$

and a standard form for a hyperbola :  $\frac{(x-h)^2}{a^2} - \frac{(y-k)^2}{b^2} = 1$

One can derive the following pairs of parametric equations to represent hyperbolas:

$$\begin{aligned}x &= a \sec t + h \\y &= b \tan t + k\end{aligned}$$

(horizontal transverse axis)

$$\begin{aligned}x &= b \tan t + h \\y &= a \sec t + k\end{aligned}$$

(vertical transverse axis)

In a hyperbola, unlike an ellipse, it makes a difference which trigonometric function corresponds with which variable.

Using the same window settings as before, re-express the equation parametrically to graph the

hyperbola  $\frac{(y-1)^2}{9} - \frac{(x+2)^2}{16} = 1$ .

### *Parabolas*

Parabolas are most easily graphed parametrically without the use of trigonometric functions. All non-rotated parabolas can either be written in the form  $y = f(x)$  or  $x = f(y)$ . Parametrically, parabolas that can be written  $y = f(x)$  can be graphed using  $x = t$  and  $y = f(t)$ , likewise parabolas that can be represented as  $x = f(y)$  can be graphed parametrically using  $x = f(t)$  and  $y = t$ . In this case the  $t$ -step of the window must be adjusted to include negative values for  $t$  or the entire parabola will not appear.

### *Rotated Conics*

Exploring rotated conic sections is an extension of this work. To do this view a pair of

parametric equations as a 2 x 1 vector matrix;  $\begin{bmatrix} x(t) \\ y(t) \end{bmatrix}$ ,

then right-multiply this matrix by a rotation matrix;  $\begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix}$ .

The resultant 2 x 1 matrix;  $\begin{bmatrix} \cos \theta \cdot x(t) - \sin \theta \cdot y(t) \\ \sin \theta \cdot x(t) + \cos \theta \cdot y(t) \end{bmatrix}$

represents a new pair of parametric equations that rotate the conic  $\theta$  degrees counter-clockwise.

In the same window graph the hyperbola from the previous example and the same hyperbola rotated  $45^\circ$  counter-clockwise.