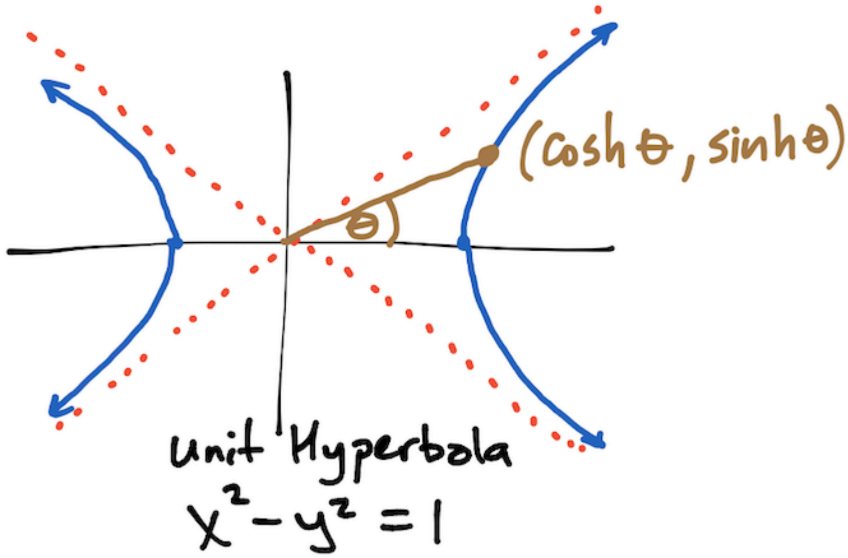
§12.5—Hyperbolic Functions

The circle has its trig functions, and the hyperbola has, what are known as, hyperbolic functions. On the Unit Circle, any point along the circle has the coordinate $(\cos\theta, \sin\theta)$. On a branch of the Unit Hyperbola, any point has the coordinate $(\cosh\theta, \sinh\theta)$.



Guess what the "h" is for . . .

We read $\cosh\theta$ as "hyperbolic cosine of theta," and $\sinh\theta$ is similarly read "hyperbolic sine of theta." Just as the circular trig functions show up in many real-world applications, so do the hyperbolic trig functions. In fact, many applications of exponential functions are really hyperbolic trig functions in disguise.

Because we will be talking about the hyperbolic **functions**, we will use x as the input, rather than θ.

Definition of the Hyperbolic Functions

$$\sinh x = \frac{e^x - e^{-x}}{2} \qquad \operatorname{csch} x = \frac{1}{\sinh x}$$

$$\cosh x = \frac{e^x + e^{-x}}{2} \qquad \operatorname{sech} x = \frac{1}{\cosh x}$$

$$\tanh x = \frac{\sinh x}{\cosh x} \qquad \coth x = \frac{1}{\tanh x}$$

Notice that the functions $f(x)=\sinh x$ and $f(x)=\cosh x$ are the differences and the sums, respectively, of the two exponential functions $y=\frac{1}{2}e^{x}$ and $y=\frac{1}{2}e^{-x}$. Because of this, the graphs of $f(x)=\sinh x$ and $f(x)=\cosh x$ can be obtained by subtracting and adding the ordinates of the two exponential graphs.

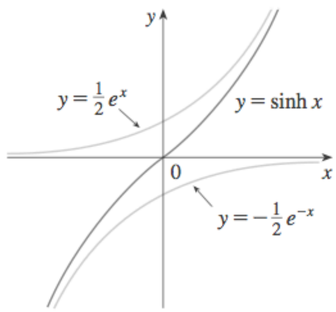


FIGURE 1
$y=\sinh x=\frac{1}{2}e^{x}-\frac{1}{2}e^{-x}$

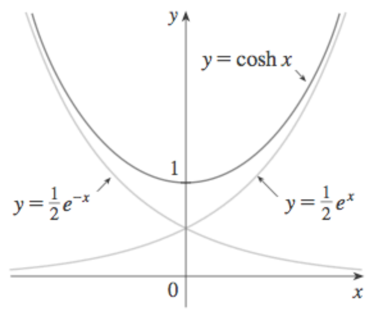


FIGURE 2
$y=\cosh x=\frac{1}{2}e^{x}+\frac{1}{2}e^{-x}$

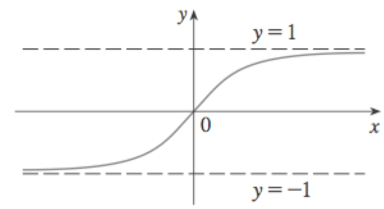


FIGURE 3
$y=\tanh x$

Example 1:
Find the domain and range and any symmetry for the three hyperbolic functions shown above.

$f(x)=\sinh x$

$D_f: \mathbb{R}$

$R_f: \mathbb{R}$

odd function

so $\sinh(-x)=-\sinh x$

$g(x)=\cosh x$

$D_g: \mathbb{R}$

$R_g: [1,\infty)$

Even Function

so $\cosh(-x)=\cosh x$

$h(x)=\tanh x$

$D_h: \mathbb{R}$

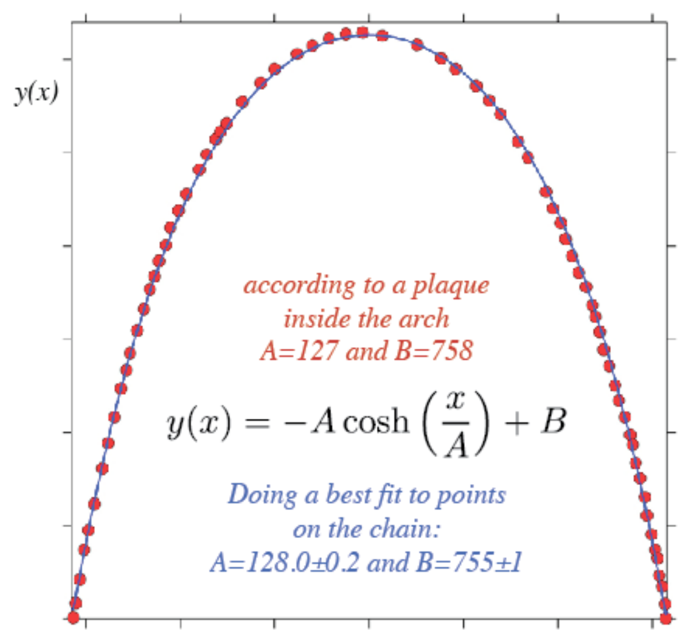
$R_h: (-1,1)$

odd function

so $\tanh(-x)=-\tanh x$

Notice how the graph of $y=\cosh x$ resembles a parabola. This mistaken identity is quite easy to make, especially without quantitative analysis. The graph of $y=\cosh x$ is actually called a **catenary curve**, from the Latin *catena*, meaning "chain." This is because a heavy chain (or cable) suspended between two fixed points at the same elevation will take the sagging shape of a catenary with equation $y=a\cosh\left(\frac{x}{a}\right)$.

The most famous catenary (and mistaken parabola) of them all is the St. Louis/Gateway Arch.



Example 2:

Using the definition of $y = \cosh x$ and $y = \sinh x$, simplify $\cosh^2 x - \sinh^2 x$.

$$(\cosh x)^2 - (\sinh x)^2$$

$$\left(\frac{e^x + e^{-x}}{2}\right)^2 - \left(\frac{e^x - e^{-x}}{2}\right)^2$$

$$\frac{e^{2x} + 2 + e^{-2x}}{4} - \frac{e^{2x} - 2 + e^{-2x}}{4}$$

$$\frac{\cancel{e^{2x}} + 2 + \cancel{e^{-2x}} - \cancel{e^{2x}} + 2 - \cancel{e^{-2x}}}{4}$$

$$\frac{4}{4}$$

$$\boxed{1}$$

So $\boxed{\cosh^2 x - \sinh^2 x = 1}$

Papa PID for Hyperbolic Functions

Just as there are many circular trig identities (and proofs), so there are many hyperbolic trig identities. For a list of many more, click here.

Let's talk calculus:

Example 3:

Using the definitions, find the derivatives of $y = \sinh x$ and $y = \cosh x$.

$$y = \sinh x$$
$$y = \tfrac{1}{2}(e^x - e^{-x})$$
$$y' = \tfrac{1}{2}(e^x + e^{-x})$$
$$y' = \cosh x$$

So $\boxed{\frac{d}{dx}\sinh x = \cosh x}$

$$y = \cosh x$$
$$y = \tfrac{1}{2}(e^x + e^{-x})$$
$$y' = \tfrac{1}{2}(e^x - e^{-x})$$
$$y' = \sinh x$$

So $\boxed{\frac{d}{dx}[\cosh x] = \sinh x}$

Example 4:

Using the definition, find the derivative of $y = \tanh x$.

$$y = \tanh x$$
$$y = \frac{\sinh x}{\cosh x}$$
$$y' = \frac{(\cosh x)(\cosh x) - (\sinh x)(\sinh x)}{\cosh^2 x}$$
$$y' = \frac{\cosh^2 x - \sinh^2 x}{\cosh^2 x}$$
$$y' = \frac{1}{\cosh^2 x}$$
$$y' = \operatorname{sech}^2 x$$

So $\boxed{\frac{d}{dx}[\tanh x] = \operatorname{sech}^2 x}$

Here are the derivatives of the Hyperbolic Functions

$$\frac{d}{dx}[\sinh u] = (\cosh u)u' \qquad \frac{d}{dx}[\coth u] = -(\operatorname{csch}^2 u)u'$$
$$\frac{d}{dx}[\cosh u] = (\sinh u)u' \qquad \frac{d}{dx}[\operatorname{sech} u] = -(\operatorname{sech} u \tanh u)u'$$
$$\frac{d}{dx}[\tanh u] = (\operatorname{sech}^2 u)u' \qquad \frac{d}{dx}[\operatorname{csch} u] = -(\operatorname{csch} u \coth u)u'$$

Example 5:

(a) $\frac{d}{dx}\left[\sinh\left(x^2-3\right)\right]=$

$\cosh(x^2-3)(2x)$

$2x\cosh(x^2-3)$

(b) $\frac{d}{dx}\left[\ln(\cosh x)\right]=$

$\frac{1}{\cosh x}\cdot(\sinh x)$

$\frac{\sinh x}{\cosh x}$

$\tanh x$

(c) $\frac{d}{dx}\left[x\sinh x-\cosh x\right]=$

$1\cdot\sinh x + x\cdot\cosh x - \sinh x$

$x\cosh x$

Example 6:

Evaluate $\int \cosh 2x \sinh^2 2x\, dx =$

$\int (\cosh(2x))\cdot(\sinh(2x))^2\,dx$

off by 2

$\left(\frac{1}{2}\right)\left(\frac{1}{3}\right)(\sinh(2x))^3 + C$

correction

$\boxed{\frac{1}{6}\sinh^3(2x) + C}$