



Bouncing Ball

Student Activity

Name _____

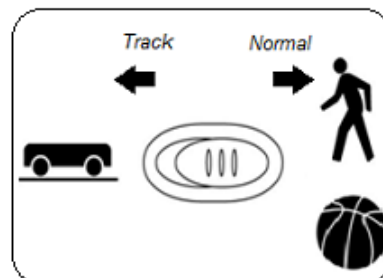
Class _____

Introduction

The height versus time data of a ball bounce can be modeled by a quadratic function. This activity investigates the time and height values at a vertex, (H, K) , and the coefficient A in the vertex form of the quadratic equation, $y = A(x - H)^2 + K$, which describes the behavior of a ball bounce.

Setup

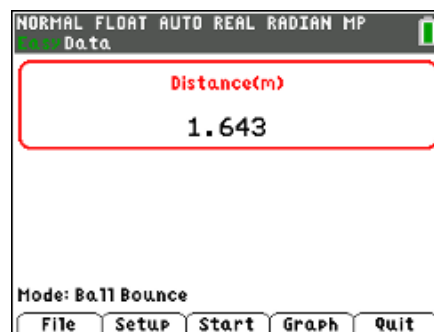
1. This activity is best performed with at least three students: one to hold the CBR™ 2 and press the trigger, one to release the ball, and one to run the calculator.
2. Lift the pivot head on the CBR™ 2 and set the sensitivity on the CBR 2 to Normal.



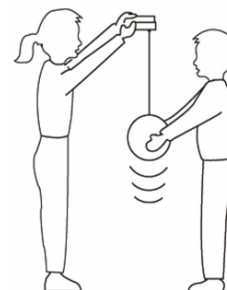
3. Attach the CBR 2 to the calculator using the CBR 2 to calculator cable. The EasyData App launches automatically when you plug in the sensor.

Note: In the EasyData App, the tabs at the bottom of the screen indicate the menus that can be accessed by pressing the calculator keys directly below the tabs.

Note: The default unit of measurement for the CBR 2 in the EasyData App is meters.



4. Practice dropping the ball under the CBR 2. This is a practice run to determine if the ball is bouncing on a flat surface.
 - Position the CBR 2 at least 15 centimeters (approximately 6 inches) above the ball.
 - Hold the sensor directly over the ball and make sure that there is nothing in the Clear Zone.
 - Hold the sides of the ball and then quickly move your hands outward to release the ball. Drop the ball (do not throw it).





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Data Collection

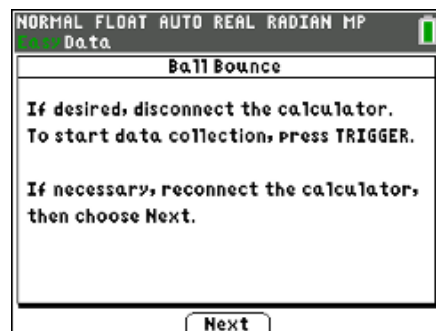
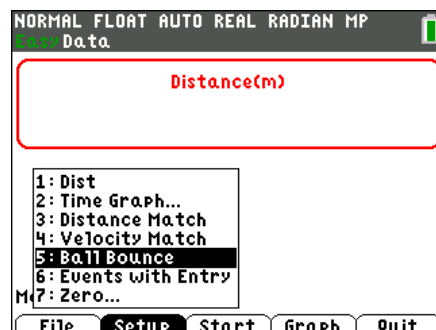
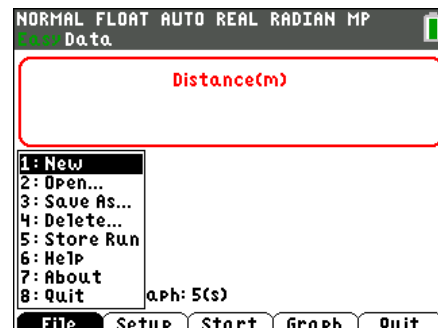
1. You cannot place the CBR 2 on the floor and bounce the ball on it, but you can use the Ball Bounce Setup option to reverse the positions so that the data will appear as though it was collected with the floor as the zero height.

- Press $\boxed{y=}$ to access the **File** menu, and select **New** to reset the application.
- Press $\boxed{\text{window}}$ to access the **Setup** menu. Select **Ball Bounce**.
- After selecting **Ball Bounce**, press $\boxed{\text{zoom}}$ to select **Start**.
- Follow the instructions displayed.

2. One person holds the CBR 2 while another person holds the ball at least 15 centimeters beneath the CBR 2. Press $\boxed{\text{zoom}}$ to select **Next**.

3. Follow the on-screen directions. At this time you may disconnect the CBR 2 from the calculator or you may leave it connected.

Important: Whether you leave the CBR 2 connected or not, you will need to press the **TRIGGER** on the CBR 2 to begin collecting data. (Do not press $\boxed{\text{zoom}}$ to select **Next** yet.)





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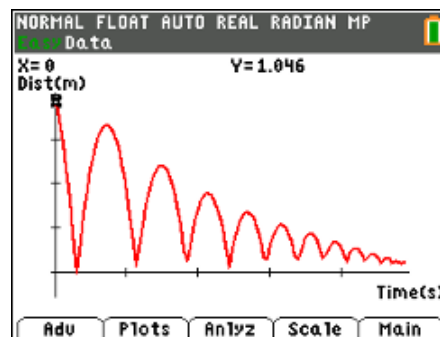
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4. When the CBR 2 begins clicking, release the ball, and then step back.
 - The program will collect data every 0.05 seconds for 5 seconds.
 - If the ball bounces to the side, move to keep the CBR 2 directly above the ball, but **be careful not to change the height of the CBR 2.**
 - When the clicking stops, reconnect the CBR 2 to the calculator (if necessary), and press **zoom** to select **Next**.
 - The collected data is transferred to the calculator. A screen displays a notice to wait as it is transferred.

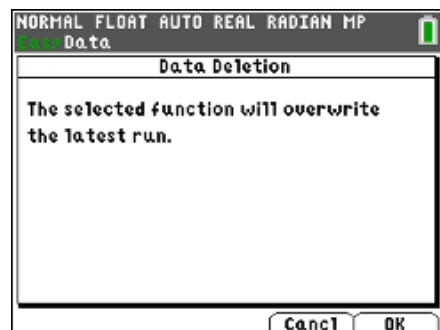
5. As soon as the data are sent, the calculator displays the distance versus time graph from within the program. The plot should look like a series of ball bounces.

The Ball Bounce Setup automatically flipped the distance data.



6. To repeat the sample, press **graph** to return to the Main screen. Press **zoom** to select **Start** and repeat the data collection process.

You will get a warning screen telling you the new data will overwrite any previous data. Press **graph** to select **OK**.



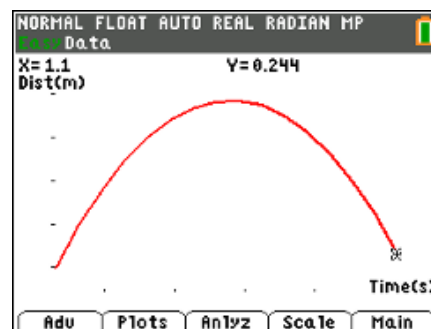
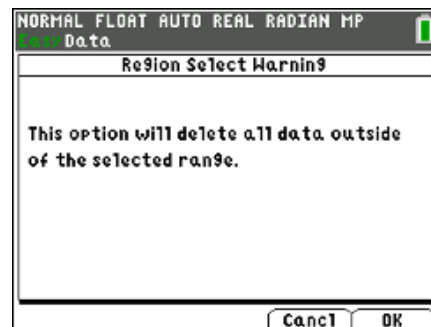
7. Use the right and left arrow keys to view the coordinates of the points. (Do not press **trace**.)
If you accidentally return to the Main screen of the EasyData App, press **trace** to select **Graph** to return to the Graph screen.
8. What quantity is represented along the horizontal axis? What are its units?
9. What quantity is represented along the vertical axis? What are its units?
10. What does the highest point on the plot represent? What does the lowest point represent?



Select a Region of the Graph and Graph Data for One Bounce

- To display the graph of one bounce, press **zoom** to select **Anlyz**, and then choose **Select Region**.

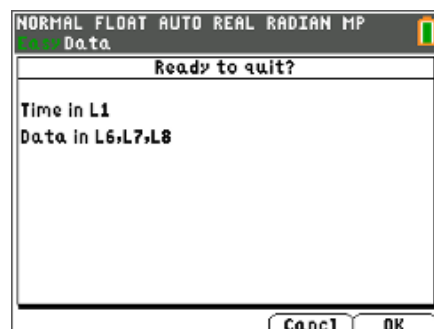
- Press **graph** to select **OK**.
- The message “Set Left Bound” is displayed.
- Arrow to the beginning of the graph of one of the parabolas, and press **graph** to select **OK**.
- The message “Set Right Bound” is displayed.
- Arrow to the end of the graph of the parabola, and press **graph** to select **OK**.
- The graph of the parabola is displayed. Note that the window settings have been changed.



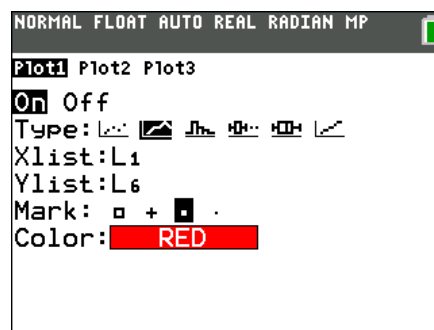
- Exit the EasyData App by pressing **graph** to select **Main**. Press **graph** again to select **Quit**.

- The app will display a screen telling you where the data are located on the calculator. For Ball Bounce, time is in **L1**, distance in **L6**, velocity in **L7**, and acceleration in **L8**.

- Press **graph** to select **OK**.



- Press **2nd** **[stat plot]**. If Plot 1 is not turned on with the configuration shown at the right, turn **Plot1** on with **L1** and **L6** for the **Xlist** and **Ylist**, respectively.



- Press **zoom** **9** to select **ZoomStat** and your data will be displayed.



Data Analysis

Method 1 – Vertex Form of a Quadratic Function; Determining the Value of A

- With the data displayed in the graph window, press **trace**, and use the arrow keys to reach a point as close to a vertex as possible.

The x- and y-coordinates displayed at the bottom of the screen will remain in the memory of the calculator (stored in x and y, respectively) until you trace to a new point or store new values in x and y.

- For any one bounce, a plot of distance vs. time has a parabolic shape. One form of the quadratic equation that describes this motion is $y = A(x - H)^2 + K$ where (H, K) is the vertex of the parabola and A is the vertical stretch or compression factor of the graph. This equation is called the *vertex form* of a quadratic equation.

Record the x- and y-coordinates of the vertex as H and K here:

$H =$ _____ $K =$ _____

- Press **2nd** **[quit]** to return to the home screen.

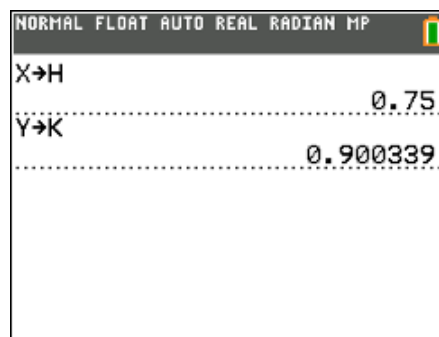
- Store the x-coordinate of the vertex in the variable H :

X,T,θ,n **sto→** **alpha** **H** **enter**

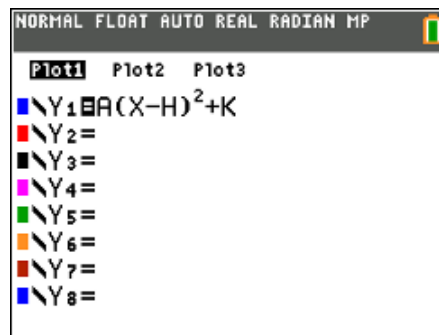
- Store the y-coordinate of the vertex in the variable K :

alpha **Y** **sto→** **alpha** **K** **enter**

Note: Sample data have been stored for H and K in the screen on the right.



- Press **y=** and enter the equation of the parabola in vertex form.



- Before storing a value for A , predict what the graph would look like if $A = 1$.
- Before storing a value for A , predict what the graph would look like if $A = 0$.



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7. To find an equation of the parabola, use a guess-and-check method to find the value of A .
 - Store a value for A on the home screen, and then press **graph** to view the graph.
 - Adjust A , as needed, by storing new values for A on the home screen.
 - For each new value of A that you store, press **graph** to view the new parabola.
 - Experiment until you find a value of A that provides a good fit for the data.
8. Record the value of A that works best: $A =$ _____
9. Using this value of A and the H and K values you reported in Step 2, write the vertex form of the quadratic equation. $y =$ _____
10. What effect does each have on the graph of the parabola?
 - a. The sign (positive or negative) of A ?
 - b. $|A| > 1$?
 - c. $|A| < 1$?
11. For the same bounce, press **trace** to trace along the bounce to identify the x - and y -coordinates of a point that is not the vertex. Record the coordinates here.
 $x =$ _____ $y =$ _____ (to 2 decimal places)
12. Substitute the coordinates of the vertex (from Step 2) and the coordinates of a point on the parabola ((x, y) from Step 11) into the vertex form of a parabola, $y = A(x - H)^2 + K$, to solve for the value of A .
 $A =$ _____
Record the equation of the parabola in vertex form.
 $y =$ _____
13. Press **y=**. Enter your equation in Y_2 , and press **graph**.
14. How does the value of A from Question 8 compare to the value of A from Question 12? Which graph (Y_1 or Y_2) provides a better fit for the bounce? Explain.



Method 2 – Using the Transformation Graphing App to Fit an Equation

1. Press $\boxed{y=}$, and delete any equations.
2. Using the data graphed for one bounce (in a ZoomStat window), use the Transfrm App to fit a quadratic function to their data.

Press $\boxed{\text{apps}}$, and select **Transfrm**.

3. Press $\boxed{y=}$, and arrow to the left of Y1. Press $\boxed{\text{enter}}$. Arrow down to the Y1 row and use the spinner on the right to select the vertex form of a quadratic equation.

Note: The coordinates of the vertex are (B, C).

4. Arrow down to OK. Press $\boxed{\text{enter}}$.

5. Press $\boxed{\text{graph}}$ to display the data for one bounce and the graph of the equation in Y1 with the last values stored for A, B, and C.

Note: Depending on the last stored values for A, B, and C, the graph of the equation in Y1 may not be visible.

6. To change values of A, B, or C, enter a value for the parameter, and press $\boxed{\text{enter}}$. To move from one parameter to another, press the up or down arrow key.

To increase or decrease the value of a parameter by 1, press the right or left arrow key. (**Note:** To increase or decrease all parameters by a different value, change the Step value. Press $\boxed{\text{graph}}$ to select **SETUP**. Arrow down to Step and enter a new Step value. Press $\boxed{\text{graph}}$ to return to the graph.)

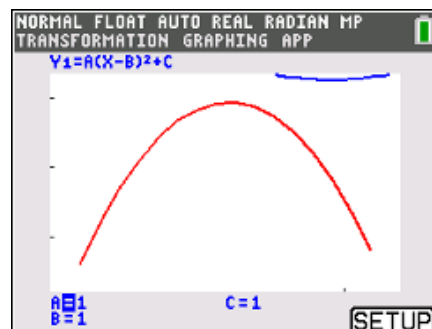
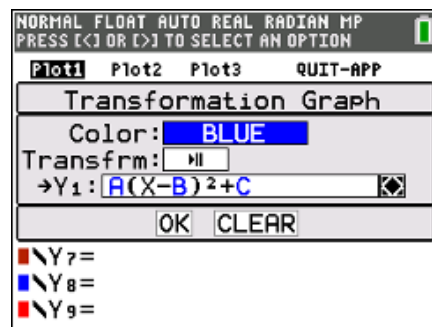
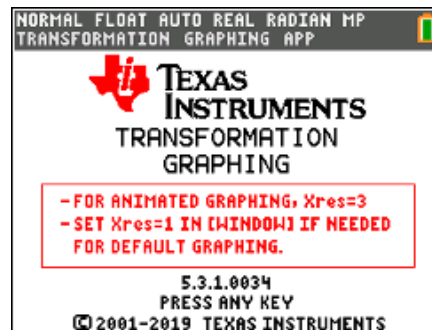
7. Change values of A, B, and C until the graph of the function provides a good model for the data.

8. Substituting the values determined for A, B, and C, record your equation.

$y = \underline{\hspace{2cm}}$

9. How does the value of A compare to the value of A determined using other methods?

10. To exit the Transfrm App, press $\boxed{y=}$, arrow to QUIT-APP, and press $\boxed{\text{enter}}$. Select **Quit Transfrm Graphing**.





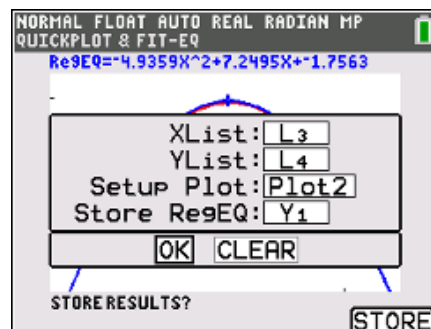
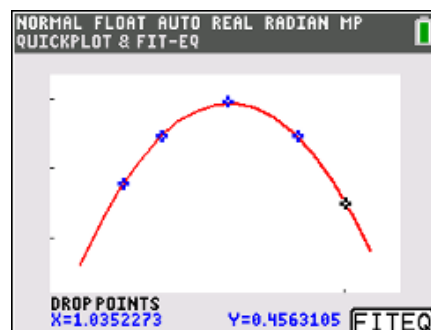
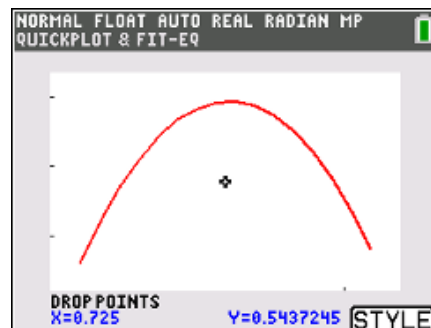
Method 3 – Using QuickPlot&Fit-EQ to Fit an Equation

- Using the data graphed for one bounce (in a ZoomStat window), determine the equation of the parabola using the Quick-Plot & Fit-EQ feature on the calculator.

- Press $\boxed{y=}$, and delete any equations.
- Press $\boxed{\text{stat}}$, and arrow to the right to **CALC**.
- Press the up or down arrow to scroll to **QuickPlot&Fit-EQ**, and then press $\boxed{\text{enter}}$.
- A blinking cursor will appear on the graph screen. Use the arrow keys to move on the graph formed by the bounce.
- To select a point on the parabola, press $\boxed{\text{enter}}$. Select at least five points – select the vertex and two points to the left and two points to the right of the vertex. (**Note:** At least three points must be selected to compute a quadratic regression equation.)
- A marked point will appear each time $\boxed{\text{enter}}$ is pressed.
- When all points have been selected, press $\boxed{\text{graph}}$ to select **FITEQ**.
- Select **QuadReg**. Press $\boxed{\text{graph}}$ to select **STORE**.
- Use the arrow keys to select **L3** for the XList, **L4** for YList, **Plot2** for Setup Plot, and **Y1** for Store RegEQ. Arrow to **OK** and press $\boxed{\text{enter}}$.

Note: Do not select L1 or L6 as that would overwrite the time and distance data from the ball bounce.

- Once **OK** is selected, the regression equation is no longer shown on the graph screen. The regression equation is stored in Y1.
- Press $\boxed{y=}$ to view the equation stored in Y1. Record the value of A. A = _____
- How does the value of A compare to the value of A determined using other methods?





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Extension:

1. Would you expect your classmates to have the same value of A for their trials, or do you think the A value would vary? Explain your answer.
2. Determine the values of A found by other groups of students in your class. How do these values compare to your value of A ?
3. If a ball that was more or less bouncy was used, would it affect the value of A in the equation? Explain your response.