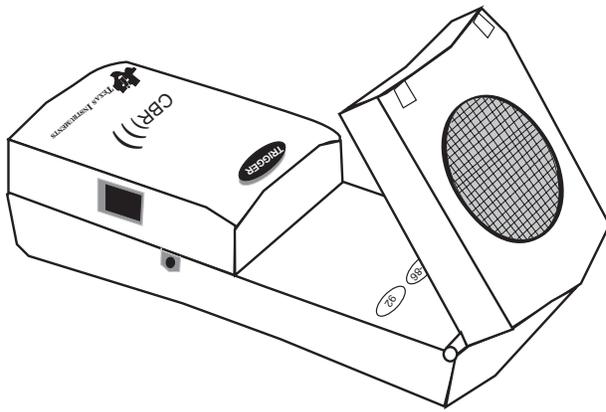


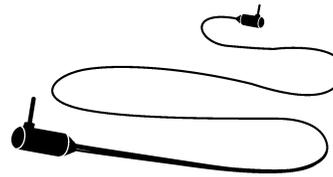
GETTING STARTED WITH CBR™

INCLUDING

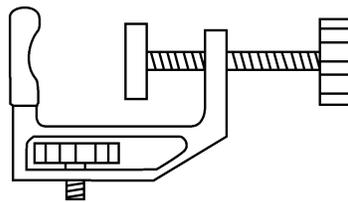
5 STUDENT ACTIVITIES



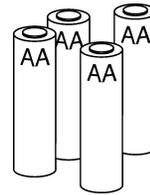
Calculator-Based Ranger™ (CBR™)



calculator-to-CBR cable



clamp



4 AA batteries

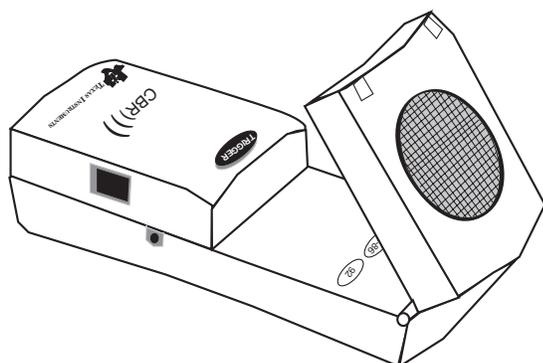
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RANGER menu map *inside back cover*

What is CBR?

CBR™ (Calculator-Based Ranger™)

sonic motion detector
use with TI-82, TI-83, TI-85/CBL, TI-86, and TI-92
bring real-world data collection and analysis into the classroom
easy-to-use, self-contained
no programming required

Includes the RANGER program

the versatile RANGER program is one button away
MATCH and BOUNCING BALL programs are built into RANGER
primary sampling parameters are easy to set

What does CBR do?

With CBR and a TI graphing calculator, students can collect, view, and analyze motion data without tedious measurements and manual plotting.

CBR lets students explore the mathematical and scientific relationships between distance, velocity, acceleration, and time using data collected from activities they perform. Students can explore math and science concepts such as:

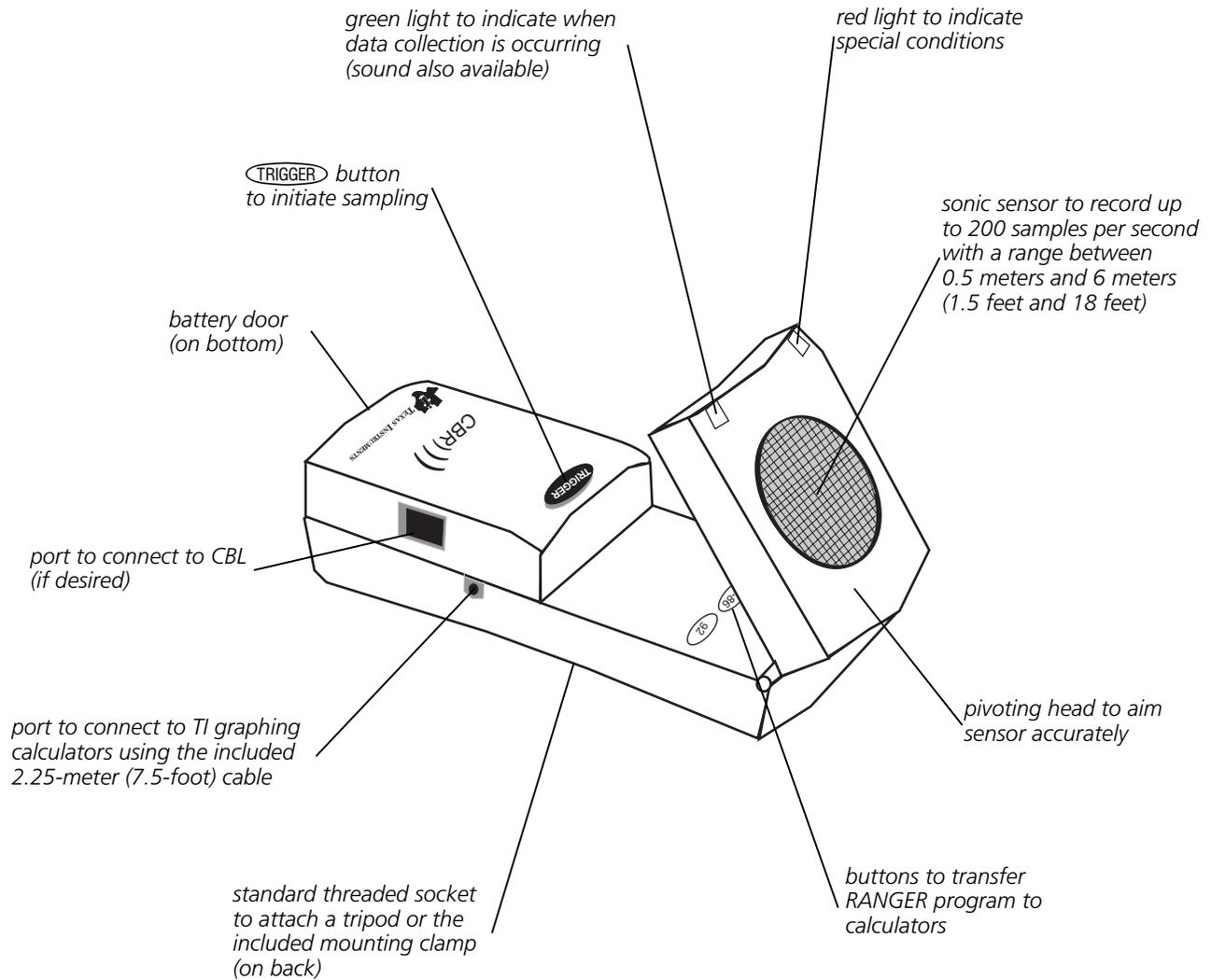
- motion: *distance, velocity, acceleration*
- graphing: *coordinate axes, slope, intercepts*
- functions: *linear, quadratic, exponential, sinusoidal*
- calculus: *derivatives, integrals*
- statistics and data analysis: *data collection methods, statistical analysis*

What's in this guide?

Getting Started with CBR™ is designed to be a guide for teachers who don't have extensive calculator or programming experience. It includes quick-start instructions for using CBR, hints on effective data collection, and five classroom activities to explore basic functions and properties of motion. The activities (see pages 13–32) include:

- teacher notes for each activity, plus general teacher information
- step-by-step instructions
- a basic data collection activity appropriate for all levels
- explorations that examine the data more closely, including what-if scenarios
- suggestions for advanced topics appropriate for precalculus and calculus students
- a reproducible student activity sheet with open-ended questions appropriate for a wide range of grade levels

What is CBR? (cont.)



CBR includes everything you need to begin classroom activities easily and quickly — just add TI graphing calculators (and readily available props for some activities).

- sonic motion detector
- calculator-to-CBR cable
- mounting clamp
- RANGER program in the CBR
- 4 AA batteries
- 5 fun classroom activities

Getting started with CBR—It's as easy as 1, 2, 3

With CBR, you're just three simple steps from the first data sample!

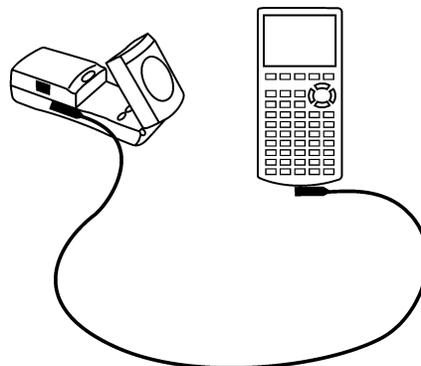
1

Connect

Connect CBR to a TI graphing calculator using the calculator-to-CBR cable.

Push in **firmly** at both ends to make the connection.

Note: The short calculator-to-calculator cable that comes with the calculator also works.



2

Transfer

RANGER, a customized program for each calculator, is in the CBR. It's easy to transfer the appropriate program from the CBR to a calculator.

First, prepare the calculator to receive the program (see keystrokes below).

TI-82 or TI-83	TI-85/CBL or TI-86	TI-92
<code>2nd</code> [LINK] <code>▶</code> <code>ENTER</code>	<code>2nd</code> [LINK] <code>F2</code>	Go to the Home screen.

Next, open the pivoting head on the CBR, and then press the appropriate program-transfer button on the CBR.

82/83

85/86

92

During transfer, the calculator displays RECEIVING (except TI-92). When the transfer is complete, the green light on CBR flashes once, CBR beeps once, and the calculator screen displays DONE. If there is a problem, the red light on CBR flashes twice and CBR beeps twice.

Once you've transferred the RANGER program from CBR to a calculator, you won't need to transfer it to that calculator again unless you delete it from the calculator's memory.

Note: The program and data require approximately 17,500 bytes of memory. You may need to delete programs and data from the calculator. You can save the programs and data first by transferring them to a computer using TI-Graph Link™ or to another calculator using a calculator-to-calculator cable or the calculator-to-CBR cable (see calculator guidebook).

3

Run

Run the RANGER program (see keystrokes below).

TI-82 or TI-83	TI-85/CBL or TI-86	TI-92
Press [PRGM] . Choose RANGER. Press [ENTER] .	Press [PRGM] [F1] . Choose RANGER. Press [ENTER] .	Press [2nd] [VAR-LINK] . Choose RANGER. Press [] [ENTER] .

The opening screen is displayed.

Press **[ENTER]**. The MAIN MENU is displayed.

MAIN MENU	
SETUP/SAMPLE	→ view/change the settings before sampling
SET DEFAULTS	→ change the settings to the default settings
APPLICATIONS	→ DISTANCE MATCH, VELOCITY MATCH, BALL BOUNCE
PLOT MENU	→ plot options
TOOLS	→ GET CBR DATA, GET CALC DATA, STATUS, STOP/CLEAR
QUIT	

From the MAIN MENU choose SET DEFAULTS. The SETUP screen is displayed. Press **[ENTER]** to choose START NOW. Set up the activity, and then press **[ENTER]** to begin data collection. It's that easy!

For quick results, try one of the classroom-ready activities in this guide!

Important information

- This guide applies to all TI graphing calculators that can be used with CBR, so you may find that some of the menu names do not match exactly those on your calculator.
- When setting up activities, ensure that the CBR is securely anchored and that the cord cannot be tripped over.
- Always exit the RANGER program using the QUIT option. The RANGER program performs a proper shutdown of CBR when you choose QUIT. This ensures that CBR is properly initialized for the next time you use it.
- Always disconnect CBR from the calculator before storing it.

Hints for effective data collection

Getting better samples

How does CBR work?

Understanding how a sonic motion detector works can help you get better data plots. The motion detector sends out an ultrasonic pulse and then measures how long it takes for that pulse to return after bouncing off the closest object.

CBR, like any sonic motion detector, measures the time interval between transmitting the ultrasonic pulse and the first returned echo, but CBR has a built-in microprocessor that does much more. When the data is collected, CBR calculates the distance of the object from the CBR using a speed-of-sound calculation. Then it computes the first and second derivatives of the distance data with respect to time to obtain velocity and acceleration data. It stores these measurements in lists L1, L2, L3, and L4.

Performing the same calculations as CBR is an interesting classroom activity.

- 1 Collect sample data in REALTIME=NO mode. Exit the RANGER program.
- 2 Use the sample times in L1 in conjunction with the distance data in L2 to calculate the velocity of the object at each sample time. Then compare the results to the velocity data in L3.

$$L3_n = \frac{(L2_{n+1} + L2_n)/2 - (L2_n + L2_{n-1})/2}{L1_{n+1} - L1_n}$$

- 3 Use the velocity data in L3 (or the student-calculated values) in conjunction with the sample times in L1 to calculate the acceleration of the object at each sample time. Then compare the results to the acceleration data in L4.

Object size

Using a small object at a far distance from the CBR decreases the chances of an accurate reading. For example, at 5 meters, you are much more likely to detect a soccer ball than a ping-pong ball.

Minimum range

When the CBR sends out a pulse, the pulse hits the object, bounces back, and is received by the CBR. If an object is closer than 0.5 meters (1.5 feet), consecutive pulses may overlap and be misidentified by CBR. The plot would be inaccurate, so position CBR at least 0.5 meters away from the object.

Maximum range

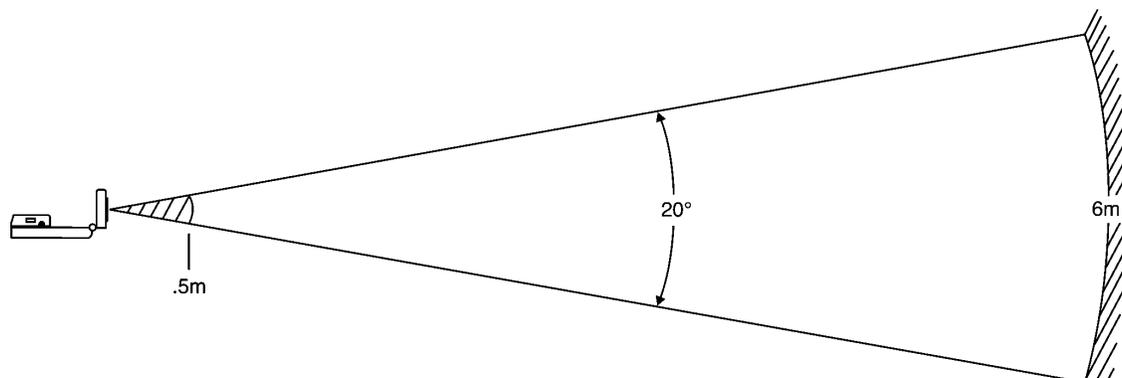
As the pulse travels through the air, it loses its strength. After about 12 meters (6 meters on the trip to the object and 6 meters on the trip back to the CBR), the return echo may be too weak to be reliably detected by the CBR. This limits the typical reliably effective distance from the CBR to the object to less than 6 meters (19 feet).

Hints for effective data collection (cont.)

The clear zone

The path of the CBR beam is not a narrow, pencil-like beam, but fans out in all directions up to 10° in a cone-shaped beam.

To avoid interference from other objects in the vicinity, try to establish a *clear zone* in the path of the CBR beam. This helps ensure that objects other than the target do not get recorded by CBR. CBR records the closest object in the clear zone.



Reflective surfaces

Some surfaces reflect pulses better than others. For example, you might see better results with a relatively hard, smooth surfaced ball than with a tennis ball. Conversely, samples taken in a room filled with hard, reflective surfaces are more likely to show stray data points. Measurements of irregular surfaces (such as a toy car or a student holding a calculator while walking) may appear uneven.

A Distance-Time plot of a nonmoving object may have small differences in the calculated distance values. If any of these values map to a different pixel, the expected flat line may show occasional blips. The Velocity-Time plot may appear even more jagged, because the change in distance between any two points over time is, by definition, velocity. You may wish to apply an appropriate degree of smoothing to the data.

Hints for effective data collection (cont.)

RANGER settings

Sample times

TIME is the total time in seconds to complete all sampling. Enter an integer between 1 second (for fast moving objects) and 99 seconds (for slow moving objects). For REALTIME=YES, TIME is always 15 seconds.

When TIME is a lower number, the object must be closer to the CBR. For example, when TIME=1 SECOND, the object can be no more than 1.75 meters (5.5 feet) from the CBR.

Starting and stopping

The SETUP screen in the RANGER program provides several options for starting and stopping sampling.

- BEGIN ON: [ENTER]. Starts sampling with the calculator's [ENTER] key when the person initiating the sampling is closest to the calculator.
- BEGIN ON: [TRIGGER]. Starts and stops sampling with the CBR (TRIGGER) button when the person initiating the sampling is closest to the CBR.
In this option, you also can choose to detach the CBR. This lets you set up the sample, disconnect the cord from the CBR, take the CBR where the action is, press (TRIGGER), sample, reattach the CBR, and press [ENTER] to transfer the data. Use BEGIN ON: [TRIGGER] when the cord is not long enough or would interfere with data collection. This is not available in REALTIME=YES mode (such as the MATCH application).
- BEGIN ON: DELAY. Starts sampling after a 10-second delay from the time you press [ENTER]. It is especially useful when only one person is doing an activity.

Trigger button

The effect of (TRIGGER) varies depending on the settings.

- (TRIGGER) starts sampling, even if BEGIN ON: [ENTER] or BEGIN ON: DELAY is selected. It also stops sampling, but usually you will want to let a sample complete.
- In REALTIME=NO, after sampling has stopped, (TRIGGER) automatically repeats the most recent sample, but does not transfer the data to the calculator. To transfer this data, from the MAIN MENU choose TOOLS, and then choose GET CBR DATA. (You also can repeat a sample by choosing REPEAT SAMPLE from the PLOT MENU or START NOW from the SETUP screen.)

Hints for effective data collection (cont.)

Smoothing

Smoothing capabilities built into the RANGER program can reduce the effect of stray signals or variations in the distance measurements. Avoid excessive smoothing. Begin with no smoothing or LIGHT smoothing. Increase the degree of smoothing until you obtain satisfactory results.

- For an activity with a higher-than-average likelihood of stray signals, you may wish to increase the smoothing on the SETUP screen before sampling (see page 38).
- For already-collected REALTIME=NO data, you can apply smoothing to the data. The calculator must be connected to the CBR. Choose PLOT TOOLS from the PLOT MENU, choose SMOOTH DATA, and then choose the degree of smoothing.

Noise—what is it and how do you get rid of it?

When the CBR receives signals reflected from objects other than the primary target, the plot shows erratic data points (noise spikes) that do not conform to the general pattern of the plot. To minimize noise:

- Make sure the CBR is pointed directly at the target. Try adjusting the sensor head while viewing a REALTIME=YES sample until you get good results before collecting a REALTIME=NO sample.
- Try to sample in a clutter-free space (see the *clear zone* drawing on page 7).
- Choose a larger, more reflective object or move the object closer to the CBR (but farther than 0.5 meters).
- When using more than one CBR in a room, one group should complete a sample before the next group begins their sample.
- For a noisy REALTIME=YES sample, repeat using a higher degree of smoothing until you obtain satisfactory results. (You cannot change the smoothing in the DISTANCE MATCH, VELOCITY MATCH, or BALL BOUNCE applications.)
- For a noisy REALTIME=NO sample, you can apply a higher degree of smoothing to the original data.

Speed of sound

The approximate distance to the object is calculated by assuming a nominal speed of sound. However, actual speed of sound varies with several factors, most notably the air temperature. For relative-motion activities, this factor is not important. For activities requiring highly accurate measurements, a programming command can be used to specify the ambient temperature (see pages 40–41).

Hints for effective data collection (cont.)

REALTIME=YES

Use REALTIME=YES mode:

- for slower objects
- to see the results as they are collected
- when you need to collect or plot only one type of data (distance, velocity, or acceleration) for a sample

In REALTIME=YES mode, the CBR processes the requested plot data (distance, velocity, or acceleration), which is transferred to the calculator following each individual distance measurement. Then RANGER plots a single pixel for that pulse.

Because all of these operations must be completed before the next sample can be requested, the maximum rate at which data can be sampled in REALTIME=YES mode is limited.

It takes approximately 0.080 seconds just to sample, process, and transfer the data for a single data point. Additional time is required for operations such as plotting the point, which slows the effective sample rate to approximately 0.125 seconds in RANGER.

REALTIME=NO

Use REALTIME=NO mode:

- for faster objects
- when smoothing is required (see page 9)
- to operate the CBR in detached mode (see page 11)
- when you need to collect or plot all types of data (distance, velocity, and acceleration) for a sample

In REALTIME=NO mode, data is stored in the CBR and not transferred to the calculator until after all sampling is completed. The sample rate can be as fast as once every 0.005 seconds for close objects. Data for time, distance, velocity, and acceleration is transferred to the calculator.

Because the data is stored in the CBR, you can transfer it from the CBR to a calculator again and again.

- Each time you change smoothing, the CBR applies the new smoothing factor, transfers the adjusted data to the calculator, and stores the smoothed values in the lists.
- Choosing a domain changes the lists stored in the calculator. If you need to, you can recover the original data from the CBR. From the MAIN MENU in the RANGER program, choose TOOLS. From the TOOLS menu, choose GET CBR DATA.
- You also can share the same data with many students, even if they are using different types of TI graphing calculators. This allows all students to participate in data analysis activities using the same data (see page 11).

Hints for effective data collection (cont.)

Using CBR in detached mode

Because the CBR cannot send data to the calculator immediately in detached mode, certain settings are required. On the SETUP screen:

- Set REALTIME=NO.
- Set BEGIN ON=[TRIGGER].

The RANGER program prompts you when to detach the CBR and when to reattach it. No special procedures are required.

Sharing data

What if you want the entire class to analyze the same data at the same time? With CBR you can disseminate REALTIME=NO data quickly within a classroom.

- ➊ Transfer the RANGER program to all students' calculators prior to data collection.
- ➋ Collect the data with the CBR in REALTIME=NO mode.
- ➌ Have the first student attach his or her calculator to the CBR using either the calculator-to-CBR cable or the calculator-to-calculator cable.
- ➍ From the MAIN MENU in the RANGER program, choose TOOLS. From the TOOLS menu, choose GET CBR DATA. TRANSFERRING... is displayed and the plot appears.
- ➎ Press **[ENTER]** to return to the PLOT MENU, and then choose QUIT. Detach the cable.
- ➏ Connect another calculator (of the same type) to the calculator with the data. On the receiving calculator, from the MAIN MENU in the RANGER program, choose TOOLS. From the TOOLS menu, choose GET CALC DATA. Instructions are displayed telling you how to set the sending calculator. When it is ready, press **[ENTER]**, and lists L1, L2, L3, L4, and L5 are transferred automatically.
- ➐ Transfer the data to another student's calculator from CBR while other students continue the calculator-to-calculator transfers.

Once all students have the same data, they can analyze the data in RANGER using the PLOT MENU or outside RANGER using the calculator's list and graphing features.

To share data on the TI-85, use the LINK feature outside of RANGER to transfer the lists.

Hints for effective data collection (cont.)

Beyond simple data collection

Once you've collected and plotted data in RANGER, you can explore the data in relationship to a function. Because the data is collected as lists and displayed as a statistical plot, you can use **TRACE**, **GRAPH**, and **Y=** to explore this relationship.

Inside RANGER

- Explore plots using TRACE, which is set automatically. (On the TI-85, use the free-moving cursor.)
- Manipulate the data set, including smoothing the data or selecting the domain of interest.

Outside RANGER

- Explore data using the calculator's list editor.
- Manually model a function to the data using the calculator's Y= editor.
- Automatically determine the equation that best fits the data using the calculator's regression capabilities.

Other relationships can be explored beyond those represented by the plot options in RANGER. For instance, simultaneous plots of Distance-Time and Velocity-Time can be viewed as statistical plots. From the MAIN MENU in the RANGER program, choose QUIT, and then set Plot1 as L1 versus L2 and Plot2 as L1 versus L3. (You may also need to adjust the Window.)

Data and plots can be sent to a computer using TI-Graph Link. This is especially useful when students generate more involved reports of their activity findings.

Using CBR without the RANGER program

You can use CBR as a sonic motion detector with CBL or with programs other than RANGER.

- For information on using CBR with CBL, see page 39.
- For information on obtaining programs and activities, see page 36.
- For information on programming commands to write your own programs, see pages 40–41.

Concepts

Function explored: linear.

MATCH introduces the real-world concepts of distance and time—or more precisely, the concept of distance *versus* time. As students attempt to duplicate graphs by walking while seeing their motion plotted, the concept of position can be explored.

In Explorations, students are asked to convert their rate of walking in meters per second to kilometers per hours.

Once they have mastered the Distance-Time match, challenge your students to a Velocity-Time match.

Materials

- ✓ calculator
- ✓ CBR
- ✓ calculator-to-calculator cable

A TI ViewScreen™ allows other students to watch—and provides much of the fun of this activity.

Hints

Students really enjoy this activity. Plan adequate time because everybody will want to try it!

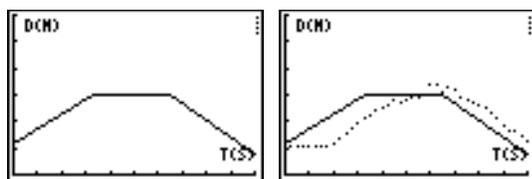
This activity works best when the student who is walking (and the entire class) can view his or her motion projected on a wall or screen using the TI ViewScreen.

Guide the students to walk in-line with the CBR; they sometimes try to walk sideways (perpendicular to the line to the CBR) or even to jump up!

Instructions suggest that the activity be done in meters, which matches the questions on the student activity sheet.

See pages 6–12 for hints on effective data collection.

Typical plots



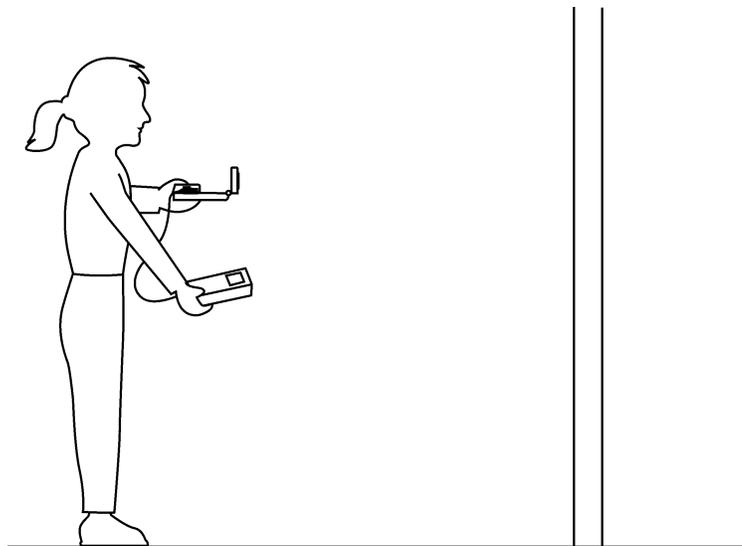
Typical answers

1. time (from start of sample); seconds; 1 second; distance (from the CBR to the object); meters; 1 meter
2. the y-intercept represents the starting distance
3. varies by student
4. backward (increase the distance between the CBR and the object)
5. forward (decrease the distance between the CBR and the object)
6. stand still; zero slope requires no change in y (distance)
7. varies by graph; $\Delta y/3.3$
8. varies by graph; $\Delta y/1$
9. the segment with the greatest slope (positive or negative)
10. this is a trick question—the flat segment, because you don't move at all!
11. walking speed; when to change direction and/or speed
12. speed (or velocity)
13. varies by graph (example: 1.5 meters in 3 seconds)
14. varies by graph; example: 0.5 meters/1 second
example: $(0.5 \text{ meters} / 1 \text{ second}) \times (60 \text{ seconds} / 1 \text{ minute}) = 30 \text{ meters} / \text{minute}$
example: $(30 \text{ meters} / 1 \text{ minute}) \times (60 \text{ minutes} / 1 \text{ hour}) = 1800 \text{ meters} / \text{hour}$
example: $(1800 \text{ meters} / 1 \text{ hour}) \times (1 \text{ kilometer} / 1000 \text{ meter}) = .18 \text{ kilometers} / \text{hour}$
Have students compare this last number to the velocity of a vehicle, say 96 kilometers / hour (60 miles per hour).
15. varies by graph; sum of the Δy for each line segment.

Data collection

- 1 Hold the CBR in one hand, and the calculator in the other. Aim the sensor directly at a wall.

Hints: The maximum distance of any graph is 4 meters (12 feet) from the CBR. The minimum range is 0.5 meters (1.5 feet). Make sure that there is nothing in the *clear zone* (see page 7).



- 2 Run the RANGER program (see page 5 for keystrokes for each calculator).
- 3 From the MAIN MENU choose APPLICATIONS. Choose METERS.
- 4 From the APPLICATIONS menu choose DISTANCE MATCH. General instructions are displayed. DISTANCE MATCH automatically takes care of the settings.
- 5 Press **ENTER** to display the graph to match. Take a moment to study the graph. **Answer questions 1 and 2 on the activity sheet.**
- 6 Position yourself where you think the graph begins. Press **ENTER** to begin data collection. You can hear a clicking sound and see the green light as the data is collected.
- 7 Walk backward and forward, and try to match the graph. Your position is plotted on the screen.
- 8 When the sample is finished, examine how well your “walk” matched the graph, and then **answer question 3.**
- 9 Press **ENTER** to display the OPTIONS menu and choose SAME MATCH. Try to improve your walking technique, and then **answer questions 4, 5, and 6.**

Explorations

In DISTANCE MATCH, all graphs are comprised of three straight-line segments.

- ① Press **ENTER** to display the OPTIONS menu and choose NEW MATCH. Study the first segment and *answer questions 7 and 8*.
- ② Study the entire graph and *answer questions 9 and 10*.
- ③ Position yourself where you think the graph begins, press **ENTER** to begin data collection, and try to match the graph.
- ④ When the sampling stops, *answer questions 11 and 12*.
- ⑤ Press **ENTER** to display the OPTIONS menu and choose NEW MATCH.
- ⑥ Study the graph and *answer questions 13, 14, and 15*.
- ⑦ Press **ENTER** to display the OPTIONS menu. Repeat the activity if desired, or return to the MAIN MENU, and then choose QUIT to exit the RANGER program.

Advanced explorations

The graphs generated by DISTANCE MATCH were all straight lines. Now try VELOCITY MATCH, in which you must match a Velocity-Time plot. This one's tough!

MATCH is a very popular program. Additional versions that explore more complicated graphs may be available (see page 36).

Activity 1—Match the graph

Name _____

Data collection

1. What physical property is represented along the x-axis? _____
What are the units? _____ How far apart are the tick marks? _____
What physical property is represented along the y-axis? _____
What are the units? _____ How far apart are the tick marks? _____
2. How far from the CBR do you think you should stand to begin? _____
3. Did you begin too close, too far, or just right? _____
4. Should you walk forward or backward for a segment that slopes up? _____
Why? _____
5. Should you walk forward or backward for a segment that slopes down? _____
Why? _____
6. What should you do for a segment that is flat? _____
Why? _____

Explorations

7. If you take one step every second, how long should that step be? _____
8. If, instead, you take steps of 1 meter (or 1 foot) in length, how many steps must you take? _____
9. For which segment will you have to move the fastest? _____
Why? _____
10. For which segment will you have to move the slowest? _____
Why? _____
11. In addition to choosing whether to move forward or backward, what other factors entered into matching the graph exactly? _____

12. What physical property does the slope, or steepness of the line segment, represent? _____
13. For the first line segment, how many meters must you walk in how many seconds? _____
14. Convert the value in question 13 (the velocity) to meters/1 second: _____
Convert to meters/minute: _____
Convert to meters/hour: _____
Convert to kilometers/hour: _____
15. How far did you actually walk? _____

Concepts

Function explored: linear.

The motion of a motorized toy car is used to illustrate the real-world concept of constant velocity.

Materials

- ✓ calculator
- ✓ CBR
- ✓ calculator-to-CBR cable
- ✓ battery-operated toy car
- ✓ TI ViewScreen (optional)

Hints

Toy cars vary greatly in size, shape, and angle of reflection of the incident ultrasonic sound. Therefore, the resulting plots may vary in quality. Some vehicles may require an additional reflective surface in order to obtain good plots. Try mounting an index card to the vehicle to assure a good target for the sensor.

You may wish to try a variety of vehicles so the students can explore these effects.

Toy cars that are slower (such as those designed for younger children) are better for this activity. Look for a car that appears to keep a constant velocity.

See pages 6–12 for hints on effective data collection.

Explorations

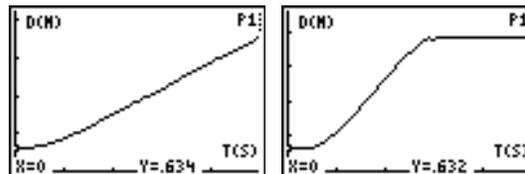
The slope of an object's Distance-Time plot at any time gives the object's speed at that time. Thus, for an object traveling at constant velocity, the slope of its Distance-Time plot is constant. This is why the Distance-Time plot exhibits a linear relationship.

If you start collecting data before the car begins moving, you will notice the Distance-Time plot is not linear at the beginning of the plot. Why? The car begins at rest ($v = 0$). It cannot instantaneously attain its constant velocity. Acceleration is given by:

$$a = \frac{\Delta v}{\Delta t}$$

In order for the object to go instantaneously from rest to its constant velocity, $\Delta t = 0$. But this implies infinite acceleration, which is not physically possible. (In fact, by Newton's Second Law, $F = ma$, an infinite acceleration could only result from an infinite force, which is equally impossible.) Thus we must observe the object accelerating (increasing its speed) to its constant velocity over a finite time period.

Typical plots



Answers to questions

1. the first or last plot; distance increases at constant rate
2. students enter values from TRACE
3. distance values increase by a constant amount
4. velocity is rate of change for distance over time; the values are the same for each equal time increment
5. student should get a value similar to the values calculated for m
similar to m
 m represents velocity or speed of car
6. b is the y-intercept; example: $y = 2x + 0$
7. varies; for example, if $m = 2$, distance (y) = 20 meters after 10 seconds ($y = 2 \times 10 + 0$); for 1 minute, $y = 120$ meters

Advanced Explorations

The slope of a Velocity-Time plot for constant velocity is zero. Therefore, the Acceleration-Time plot shows $a = 0$ (in the ideal case) over the time period where velocity is constant.

The resulting area is the object's displacement (net distance traveled) during the time interval t_1 to t_2 .

For calculus students, the displacement can be found from:

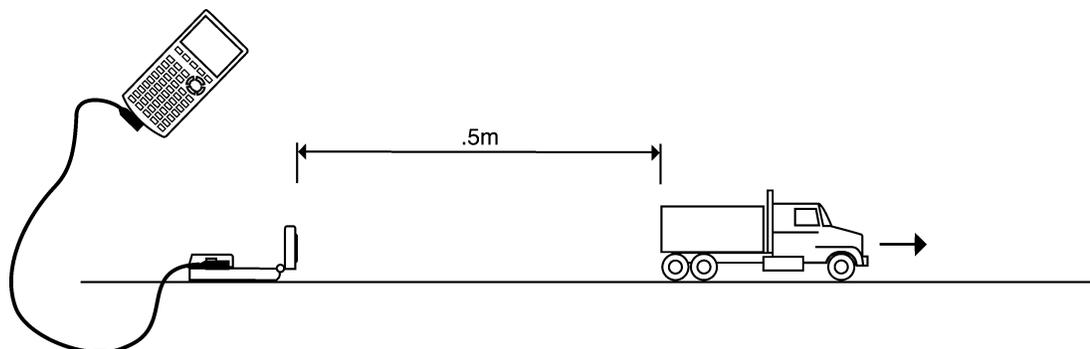
$$s = \int_{t_1}^{t_2} v dt$$

where s is the object's displacement in the interval t_1 to t_2 .

Data collection

- 1 Position the car at least 0.5 meters (1.5 feet) from the CBR, facing away from the CBR in a straight line.

Hints: Aim the sensor directly at the car and make sure that there is nothing in the *clear zone* (see page 7).



- 2 Before starting data collection, *answer question 1 on the activity sheet*.
- 3 Run the RANGER program (see page 5 for keystrokes for each calculator).
- 4 From the MAIN MENU choose SETUP/SAMPLE. For this activity, the settings should be:

```

REALTIME:  NO
TIME (S):  5 SECONDS
DISPLAY:   DISTANCE
BEGIN ON:  [ENTER]
SMOOTHING: LIGHT
UNITS:     METERS
    
```

Instructions for changing a setting are on page 38.

- 5 Choose START NOW.
- 6 Press **[ENTER]** when you are ready to begin. Start the car and quickly move out of the *clear zone*. You can hear a clicking sound as the data is collected and the message TRANSFERRING... is displayed on the calculator.
- 7 When the data collection is concluded, the calculator automatically displays a Distance-Time plot of the collected data points.
- 8 Compare the plot of the data results to your prediction in *answer 1* for similarities and differences.

Explorations

- ① The values for x (time) in half-second intervals are in the first column in question 2. **Trace the plot and enter the corresponding y (distance) values in the second column. Note:** Include results only from the linear part of the plot. You may need to disregard inconsistent data at the beginning of the data collection. Also, you may need to approximate the distance (the calculator may give you distance for 0.957 and 1.01 seconds instead of exactly 1 second). Pick the closest one or take your best guess.
- ② Answer questions 3 and 4.
- ③ Calculate the changes in distance and time between each data point to complete the third and fourth columns. For example, to calculate Δ Distance (meters) for 1.5 seconds, subtract Distance at 1 second from Distance at 1.5 seconds.
- ④ The function illustrated by this activity is $y = mx + b$. m is the slope of a line. It is calculated by:

$$\frac{\Delta \text{distance}}{\Delta \text{time}} \text{ or } \frac{\text{distance}_2 - \text{distance}_1}{\text{time}_2 - \text{time}_1} \text{ or } \frac{y_2 - y_1}{x_2 - x_1}$$

The y-intercept represents b .

Calculate m for every point. **Enter the values in the table in question 2.**

- ⑤ Answer questions 5, 6, and 7.

Advanced Explorations

Calculating the slope of a Distance-Time plot at any time gives the object's approximate velocity at that time. Calculating the slope of a Velocity-Time plot gives the object's approximate acceleration at that time. If velocity is constant, what does acceleration equal?

Predict what the Acceleration-Time plot for this Distance-Time plot looks like.

Find the area between the Velocity-Time plot and the x-axis between any two convenient times, t_1 and t_2 . This can be done by summing the areas of one or more rectangles, each with an area given by:

$$\text{area} = v\Delta t = v(t_2 - t_1)$$

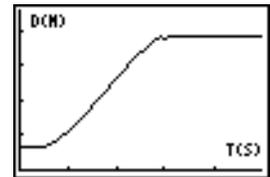
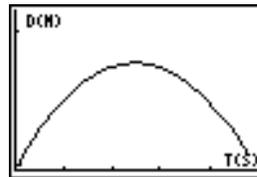
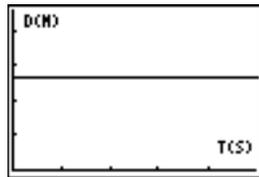
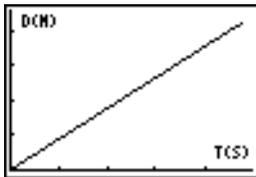
What is the physical significance of the resulting area?

Activity 2—Toy car

Name _____

Data collection

1. Which of these do you think will match the *Distance-Time* plot of the toy car?



Why? _____

2.

Time	Distance	Δ Distance	Δ Time	m
1		xxx	xxx	xxx
1.5				
2				
2.5				
3				
3.5				
4				
4.5				
5				

3. What do you notice about the Distance values? _____

4. How do these results show that the toy car had constant velocity? _____

5. Calculate Δ distance/ Δ time between Time = 2 and Time = 4. _____

What did you notice about this result? _____

What do you think m represents? _____

6. For the linear equation $y = mx + b$, what is the value for b ? _____

Write the equation for the line in the $y = mx + b$ form, using values for m and b . _____

7. How far would the toy car travel in 10 seconds? _____

In 1 minute? _____

Concepts

Function explored: sinusoidal.

Explore simple harmonic motion by observing a free-swinging pendulum.

Materials

- ✓ calculator
- ✓ CBR
- ✓ calculator-to-CBR cable
- ✓ mounting clamp
- ✓ stopwatch
- ✓ pendulum
- ✓ meter stick
- ✓ TI ViewScreen (optional)

Ideas for weights:

- balls of different sizes (≥ 2 " diameter)
- soda cans (empty and filled)
- bean bags

Hints

See pages 6–12 for hints on effective data collection.

Physical connections

An object that undergoes periodic motion resulting from a restoring force proportional to its displacement from its equilibrium (rest) position is said to exhibit simple harmonic motion (SHM). SHM can be described by two quantities.

- The period T is the time for one complete cycle.
- The amplitude A is the maximum displacement of the object from its *equilibrium position* (the position of the weight when at rest).

For a simple pendulum, the period T is given by:

$$T = 2\pi \sqrt{\frac{L}{g}}$$

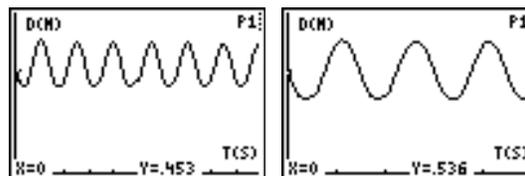
where L is the string length and g is the magnitude of the acceleration due to gravity. T does not depend on the mass of the object or the amplitude of its motion (for small angles).

The frequency f (number of complete cycles per second) can be found from:

$$f = \frac{1}{T}, \text{ where } f \text{ is in hertz (Hz) when } T \text{ is in seconds.}$$

The derivatives of a sinusoidal plot are also sinusoidal. Note particularly the phase relationship between the weight's position and velocity.

Typical plots



Typical answers

1. varies (in meters)
2. varies (in meters)
3. varies (in seconds); T (one period) = total time of 10 periods/10; averaging over a larger sample tends to minimize inherent measurement errors
4. the total arc length, which should be approximately 4 times the answer to question 2; because an arc is longer than a straight line
5. sinusoidal, repetitive, periodic; distance from the x-axis to the equilibrium position
6. each cycle is spread out horizontally; a plot spanning 10 seconds must fit more cycles in same amount of screen space, therefore cycles appear closer together
7. (total # of cycles)/(5 seconds) = cycles/second; easier to view full cycles, and fewer measurement errors
8. $f = 1/T$, where T is time for 1 period
9. decreased period; increased period
(Pendulum length is directly related to period time; the longer the string, the longer the period. Students can explore this relationship using the calculator's list editor, where they can calculate the period for various values of L .)
10. A (amplitude) = $\frac{1}{4}$ total distance that the pendulum travels in 1 period
11. both sinusoidal; differences are in amplitude and phase
12. equilibrium position
13. when position = maximum or minimum value (when the weight is at greatest distance from equilibrium).
14. It doesn't. T depends only on L and g , not mass.

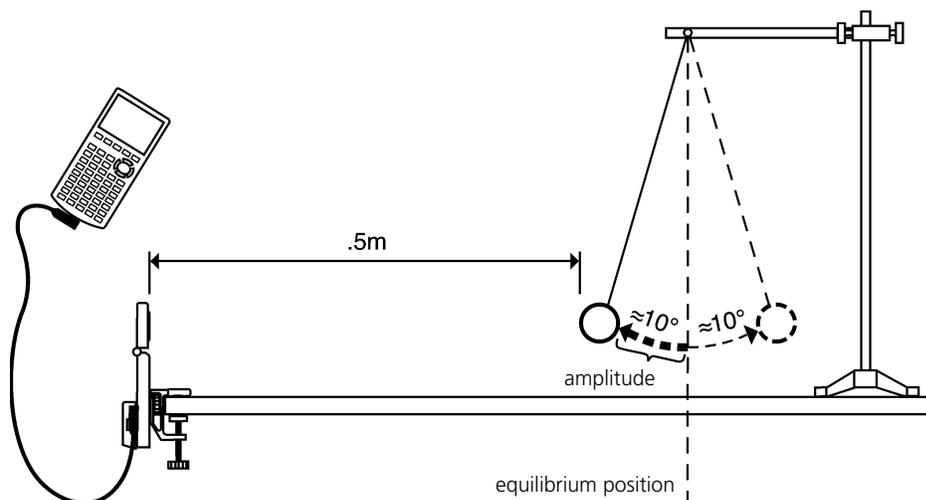
Advanced explorations

Data collection: the plot of L2 versus L3 forms an ellipse.

Data collection

- 1 Set up the pendulum. Align the pendulum so it swings in a direct line with the CBR.

Hints: Position the CBR at least 0.5 meters (1.5 feet) from the closest approach of the weight. Make sure that there is nothing in the *clear zone* (see page 7).



- 2 Using a meter stick, measure the distance from the CBR to the equilibrium position. **Answer question 1 on the activity sheet.**
Measure how far you will you pull the weight away from the equilibrium position. **Answer question 2.**
- 3 A pendulum cycle (a *period*) consists of one complete swing back and forth. Using a stopwatch, time ten full periods. **Answer questions 3 and 4.**
- 4 Run the RANGER program (see page 5 for keystrokes for each calculator). An efficient method is for one person start the pendulum while another operates the calculator and CBR. From the MAIN MENU choose SETUP/SAMPLE.
- 5 Press **[ENTER]** to display the settings. For this activity, they should be:

```

REALTIME: NO
TIME (S): 10 SECONDS
DISPLAY: DISTANCE
BEGIN ON: [ENTER]
SMOOTHING: LIGHT
UNITS: METERS
    
```

- 6 Instructions for changing a setting are on page 38. When they are correct, choose START NOW.
- 7 Press **[ENTER]** when you are ready to begin. You can hear a clicking sound as the data is collected, and the message TRANSFERRING... is displayed on the calculator.
- 8 When the data collection is complete, the calculator automatically displays a Distance-Time plot of the collected data points. **Answer question 5.**

Explorations**Data collection 2**

From the MAIN MENU choose SETUP/SAMPLE. On the SETUP screen, change the time from 10 to 5 seconds. Repeat the data collection. Observe the plot. *Answer questions 6 and 7.*

The quantity you determined (cycles per second) is called the *frequency*. Although you calculated frequency in question 7 using the plot, you can find it mathematically from:

$$f = \frac{1}{T} \quad \text{where } T \text{ is the period in seconds, and } f \text{ is the frequency in hertz (Hz).}$$

Answer question 8.

Data collections 3 and 4

Repeat the 5-second data collection two more times. First, shorten the string. Second, lengthen the string. After observing those plots, *answer question 9.*

Another important distance measurement affecting the motion of the pendulum is the *amplitude*. The answer to question 2 was the amplitude of that pendulum swing. *Answer question 10.*

Advanced explorations**Data collection 5**

From the PLOT MENU choose VELOCITY-TIME. *Answer questions 11, 12 and 13.*

Data collection 6

Repeat the data collection with a significantly lighter or heavier weight, and then *answer question 14.*

Model the distance-time behavior of the pendulum using the form for a sinusoidal function, $S = A \sin(\omega t + \delta)$, where S is the instantaneous position, A is the amplitude, ω is the frequency, δ is the phase angle, and t is the time. The frequency, ω , is related to the period, T , by $\omega = 2\pi/T$.

Enter this equation in the Y= editor using the calculated values of A and ω . Simultaneously graph this function and the statistical plot of L1 (time) versus L2 (distance). Adjust the values of A , ω , and δ until a good fit is obtained. On the TI-83 or TI-86, use the sine regression to determine the values.

Explore the relationship between position and velocity by plotting L2 (distance) versus L3 (velocity). What do you predict for the appearance of the resulting plot? Compare the actual result to your prediction.

Activity 3—Pendulum

Name _____

Data collection

1. What is the distance from CBR to the equilibrium position? _____

2. How far will you pull the pendulum away from the equilibrium position? _____

3. What was the time for ten periods? _____

Calculate how long (in seconds) it took to complete one period. _____

What is the benefit of timing ten complete periods instead of just one? _____

4. Use the answer to question 2, and approximate the total distance traveled in one cycle. _____

Why is this value shorter than the actual distance traveled in one cycle? _____

5. What do you notice about the shape of the plot? _____

How is the value from question 1 represented on the plot? _____

Explorations

6. How does the appearance of the plot change? Why? _____

7. Using data collected from your plot, calculate the number of complete cycles per second. _____

Why is it easier to determine this using the second plot (spanning 5 seconds) rather than the first one (spanning 10 seconds)? _____

8. Calculate the frequency for one period using the equation. _____

9. How does shortening the string length affect the period of the pendulum? _____

How does lengthening the string affect the period of the pendulum? _____

10. What is the relationship between the amplitude of the pendulum swing and the total distance that the pendulum travels in one period? _____

Advanced explorations

11. Compare the Distance-Time plot with the Velocity-Time plot. List similarities and differences. _____

12. In what position is the weight's velocity maximum? _____

13. In what position is the weight's velocity minimum? _____

14. How does changing the weight affect the plot? Why? _____

Concepts

Function explored: parabolic.

Real-world concepts such as free-falling and bouncing objects, gravity, and constant acceleration are examples of parabolic functions. This activity investigates the values of height, time, and the coefficient A in the quadratic equation, $Y = A(X - H)^2 + K$, which describes the behavior of a bouncing ball.

Materials

- ✓ calculator
- ✓ CBR
- ✓ calculator-to-CBR cable
- ✓ large (9-inch) playground ball
- ✓ TI ViewScreen (optional)

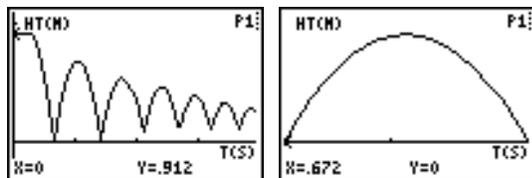
Hints

This activity is best performed with two students, one to hold the ball and the other to push **TRIGGER**.

See pages 6–12 for hints on effective data collection.

The plot should look like a bouncing ball. If it does not, repeat the sample, ensuring that the CBR is aimed squarely at the ball. A large ball is recommended.

Typical plots



Explorations

After an object is released, it is acted upon only by gravity (neglecting air resistance). So A depends on the acceleration due to gravity, -9.8 meters/second² (-32 feet/second²). The negative sign indicates that the acceleration is downward.

The value for A is approximately one-half the acceleration due to gravity, or -4.9 meters/second² (-16 feet/second²).

Typical answers

1. time (from start of sample); seconds; height / distance of the ball above the floor; meters or feet
2. initial height of the ball above the floor (the peaks represent the maximum height of each bounce); the floor is represented by $y = 0$.

3. The Distance-Time plot for this activity does not represent the distance from the CBR to the ball. BALL BOUNCE flips the distance data so the plot better matches students' perceptions of the ball's behavior. $y = 0$ on the plot is actually the point at which the ball is farthest from the CBR, when the ball hits the floor.
4. Students should realize that the x-axis represents time, not horizontal distance.
7. The graph for $A = 1$ is both inverted and broader than the plot.
8. $A < -1$
9. parabola concave up; concave down; linear
12. same; mathematically, the coefficient A represents the extent of curvature of the parabola; physically, A depends upon the acceleration due to gravity, which remains constant through all the bounces.

Advanced explorations

The rebound height of the ball (maximum height for a given bounce) is approximated by:

$$y = hp^x, \text{ where}$$

- y is the rebound height
- h is the height from which the ball is released
- p is a constant that depends on physical characteristics of the ball and the floor surface
- x is the bounce number

For a given ball and initial height, the rebound height decreases exponentially for each successive bounce. When $x = 0$, $y = h$, so the y-intercept represents the initial release height.

Ambitious students can find the coefficients in this equation using the collected data. Repeat the activity for different initial heights or with a different ball or floor surface.

After manually fitting the curve, students can use regression analysis to find the function that best models the data. Select a single bounce using PLOT TOOLS, SELECT DOMAIN. Then QUIT from the MAIN MENU. Follow the calculator operating procedures to perform a quadratic regression on lists L1 and L2.

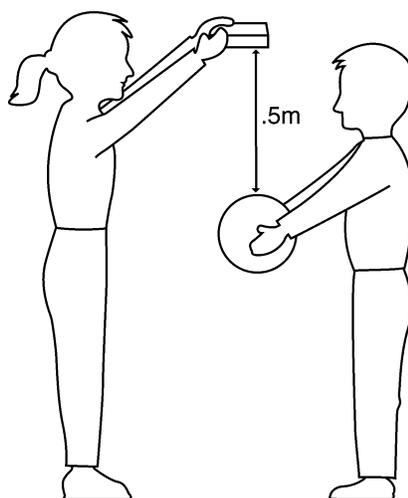
Extensions

Integrate under Velocity-Time plot, giving the displacement (net distance traveled) for any chosen time interval. Note the displacement is zero for any full bounce (ball starts and finishes on floor).

Data collection

- 1 Begin with a test bounce. Drop the ball (do not throw it).

Hints: Position the CBR at least 0.5 meters (1.5 feet) above the height of the highest bounce. Hold the sensor directly over the ball and make sure that there is nothing in the clear zone (see page 7).



- 2 Run the RANGER program (see page 5 for keystrokes for each calculator).
- 3 From the MAIN MENU choose APPLICATIONS. Choose METERS or FEET.
- 4 From the APPLICATIONS menu choose BALL BOUNCE. General instructions are displayed. BALL BOUNCE automatically takes care of the settings.
- 5 Hold the ball with arms extended. Press **ENTER**. The RANGER program is now in Trigger mode. At this point, you may detach CBR from the calculator.
- 6 Press **TRIGGER**. When the green light begins flashing, release the ball, and then step back. (If the ball bounces to the side, move to keep the CBR directly above the ball, but be careful **not** to change the height of the CBR.)

You can hear a clicking sound as the data is collected. Data is collected for time and distance, and calculated for velocity and acceleration. If you have detached the CBR, reattach it when data collection is finished.

- 7 Press **ENTER**. (If the plot doesn't look good, repeat the sample.) Study the plot. **Answer questions 1 and 2 on the activity sheet.**
- 8 Observe that BALL BOUNCE automatically flipped the distance data. **Answer questions 3 and 4.**

Explorations

The Distance-Time plot of the bounce forms a parabola.

- 1 Press **[ENTER]**. From the PLOT MENU, choose PLOT TOOLS, and then SELECT DOMAIN. We want to select the first full bounce. Move the cursor to the base of the beginning of the bounce, and press **[ENTER]**. Move the cursor to the base at the end of that bounce, and then press **[ENTER]**. The plot is redrawn, focusing on a single bounce.
- 2 The plot is in TRACE mode. Determine the vertex of the bounce. *Answer question 5* on the activity sheet.
- 3 Press **[ENTER]** to return to the PLOT MENU. Choose MAIN MENU. Choose QUIT.
- 4 The *vertex form* of the quadratic equation, $Y = A(X - H)^2 + K$, is appropriate for this analysis. Press **[Y=]**. In the Y= editor, turn off any functions that are selected. Enter the vertex form of the quadratic equation: $Yn=A*(X-H)^2+K$.
- 5 On the Home screen, store the value you recorded in question 5 for the height in variable K ; store the corresponding time in variable H ; store 1 in variable A .
- 6 Press **[GRAPH]** to display the graph. *Answer questions 6 and 7.*
- 7 Try $A = 2, 0, -1$. *Complete the first part of the chart in question 8 and answer question 9.*
- 8 Choose values of your own for A until you have a good match for the plot. *Record your choices for A in the chart in question 8.*
- 9 Repeat the activity, but this time choose the last (right-most) full bounce. *Answer questions 10, 11, and 12.*

Advanced explorations

- 1 Repeat the data collection, but do not choose a single parabola.
- 2 Record the time and height for each successive bounce.
- 3 Determine the ratio between the heights for each successive bounce.
- 4 Explain the significance, if any, of this ratio.

Activity 4—Bouncing ball

Name _____

Data collection

1. What physical property is represented along the x-axis? _____
What are the units? _____
What physical property is represented along the y-axis? _____
What are the units? _____
2. What does the highest point on the plot represent? _____
The lowest point? _____
3. Why did the BALL BOUNCE program flip the plot? _____
4. Why does the plot look like the ball bounced across the floor? _____

Explorations

5. Record the maximum height and corresponding time for the first full bounce. _____
6. Did the graph for $A = 1$ match your plot? _____
7. Why or why not? _____
8. Complete the chart below.

A	How do the data plot and the Y_n graph compare?
1	
2	
0	
-1	

9. What does a positive value for A imply? _____
What does a negative value for A imply? _____
What does a zero value for A imply? _____
10. Record the maximum height and corresponding time for the last full bounce. _____
11. Do you think A will be bigger or smaller for the last bounce? _____
12. How did A compare? _____
What do you think A might represent? _____

Concepts

Function explored: parabolic.

Plotting a ball rolling down a ramp of varying inclines creates a family of curves, which can be modeled by a series of quadratic equations. This activity investigates the values of the coefficients in the quadratic equation, $y = ax^2 + bx + c$.

Materials

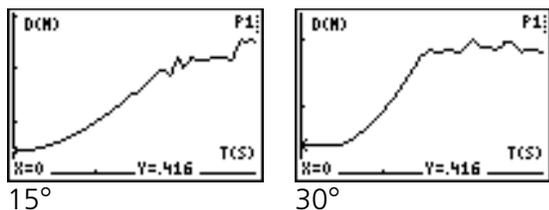
- ✓ calculator
- ✓ CBR
- ✓ calculator-to-CBR cable
- ✓ mounting clamp
- ✓ large (9 inch) playground ball
- ✓ long ramp (at least 2 meters or 6 feet—a lightweight board works well)
- ✓ protractor to measure angles
- ✓ books to prop up ramp
- ✓ TI ViewScreen (optional)

Hints

Discuss how to measure the angle of the ramp. Let students get creative here. They might use a trigonometric calculation, folded paper, or a protractor.

See pages 6–12 for hints on effective data collection.

Typical plots



Typical answers

1. the third plot
2. time; seconds; distance of object from CBR; feet or meters

3. varies (should be half of a parabola, concave up)
4. a parabola (quadratic)
5. varies
6. varies (should be parabolic with increasing curvature)
7. 0° is flat (ball can't roll); 90° is the same as a free-falling (dropping) ball

Explorations

The motion of a body acted upon only by gravity is a popular topic in a study of physical sciences. Such motion is typically expressed by a particular form of the quadratic equation,

$$s = \frac{1}{2}at^2 + v_i t + s_i \text{ where}$$

- s is the position of an object at time t
- a is its acceleration
- v_i is its initial velocity
- s_i is its initial position

In the quadratic equation $y = ax^2 + bx + c$, y represents the distance from the CBR to the ball at time x if the ball's initial position was c , initial velocity was b , and acceleration is $2a$.

Advanced explorations:

Since the ball is at rest when released, b should approach zero for each trial. c should approach the initial distance, 0.5 meters (1.5 feet). a increases as the angle of inclination increases.

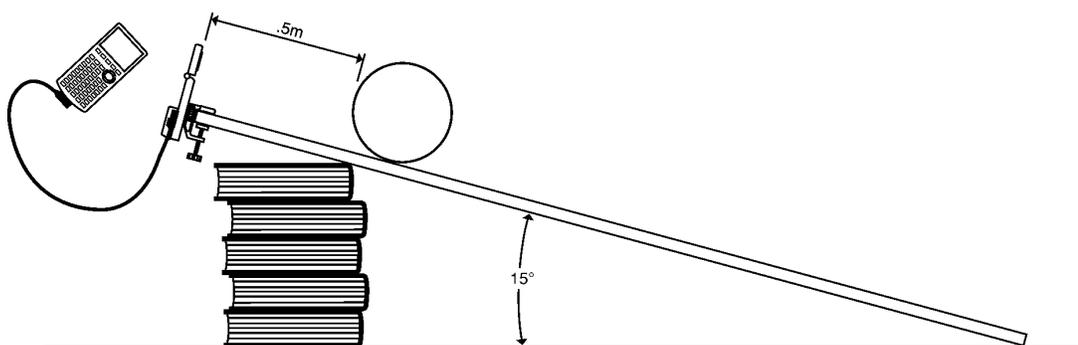
If students model the equation $y = ax^2 + bx + c$ manually, you may need to provide hints for the values of b and c . You may also direct them to perform a quadratic regression on lists L1, L2 using their calculators. The ball's acceleration is due to the earth's gravity. So the more the ramp points down (the greater the angle of inclination), the greater the value of a . Maximum a occurs for $\theta = 90^\circ$, minimum for $\theta = 0^\circ$. In fact, a is proportional to the sine of θ .

Data collection

- 1 Answer question 1 on the activity sheet. Set the ramp at a 15° incline. Attach the clamp to the top edge of the ramp. Attach the CBR to the clamp. Open the sensor head and position it perpendicular to the ramp. Attach the calculator to the CBR.

Mark a spot on the ramp 0.5 meters (1.5 feet) from the CBR. Have one student hold the ball at this mark, while a second student holds the calculator.

Hints: Aim the sensor directly at the ball and make sure that there is nothing in the clear zone (see page 7).



- 2 Run the RANGER program (see page 5 for keystrokes for each calculator). From the MAIN MENU choose SETUP/SAMPLE.
- 3 Press **[ENTER]** to display the settings. For this activity, they should be:

REALTIME: NO
TIME (S): 3 SECONDS
DISPLAY: DISTANCE
BEGIN ON: [ENTER]
SMOOTHING: LIGHT
UNITS: METERS

Instructions for changing a setting are on page 38.

- 4 When the settings are correct, choose START NOW. Press **[ENTER]** to begin sampling.
- 5 When the clicking begins, release the ball immediately (don't push) and step back.
- 6 When the sample is complete, the Distance-Time plot is displayed automatically. **Answer questions 2 and 3.**
- 7 Press **[ENTER]** to display the PLOT MENU. Choose PLOT TOOLS, and then choose SELECT DOMAIN. Move the cursor to where the ball was released, and then press **[ENTER]**. Move the cursor to where the ball reached the end of the ramp, and then press **[ENTER]**. The plot is redrawn, focusing on the portion of the sample that corresponds to the ball rolling down the ramp. **Answer questions 4 and 5.**

Explorations

Examine what happens for differing inclines.

- 1 Predict what will happen if the incline increases. *Answer question 6.*
- 2 Adjust the incline to 30° . Repeat steps 2 through 6. *Add this plot to the drawing in question 6, labeled 30° .*
- 3 Repeat steps 2 through 6 for inclines of 45° and 60° and add to the drawing.
- 4 *Answer question 7.*

Advanced explorations

Adjust the time values so that $x = 0$ for the initial height (the time at which the ball was released). You can do this manually by subtracting the x value for the first point from all the points on your plot, or you can enter $L1(1) \rightarrow A: L1 - A \rightarrow L1$.

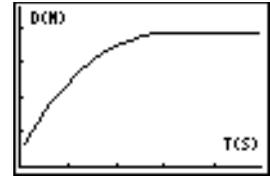
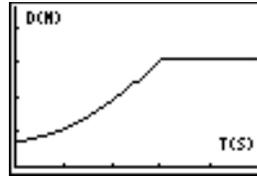
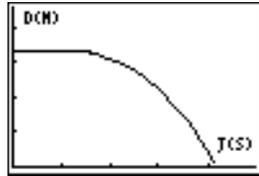
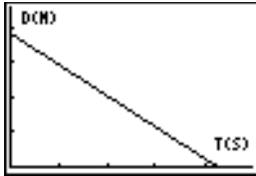
- 1 Calculate the values for a , b , and c for the family of curves in the form $y = ax^2 + bx + c$ at 0° , 15° , 30° , 45° , 60° , 90° .
- 2 What are the minimum and maximum values for a ? Why?
- 3 Write an expression describing the mathematical relationship between a and the angle of inclination.

Activity 5—Rolling ball

Name _____

Data collection

1. Which of these plots do you think best matches the *Distance-Time* plot of a ball rolling down a ramp?



2. What physical property is represented along the x-axis? _____

What are the units? _____

What physical property is represented along the y-axis? _____

What are the units? _____

3. Sketch what the plot really looks like. Label the axis. Label the plot at the points when the ball was released and when it reached the end of the ramp.



4. What type of function does this plot represent? _____

5. Discuss your change in understanding between the graph you chose in question 1 and the curve you sketched in question 3. _____

Explorations

6. Sketch what you think the plot will look like with a greater incline. (Label it *prediction*.)



7. Sketch and label the plots for 0° and 90° :



Teacher information

How might your classes change with CBR?

CBR is an easy-to-use system with features that help you integrate it into your lesson plans quickly and easily.

CBR offers significant improvements over other data-collection methods you may have used in the past. This, in turn, may lead to a restructuring of how you use class time, as your students become more enthusiastic about using real-world data.

- You'll find that your students feel a greater sense of ownership of the data because they actually participate in the data-collection process rather than using data from textbooks, periodicals, or statistical abstracts. This impresses upon them that the concepts you explore in class are connected to the real world and aren't just abstract ideas. But it also means that each student will want to take his or her turn at collecting the data.
- Data collection with CBR is considerably more effective than creating scenarios and manually taking measurements with a ruler and stopwatch. Since more sampling points give greater resolution and since a sonic motion detector is highly accurate, the shape of curves is more readily apparent. You will need less time for data collection and have more time for analysis and exploration.
- With CBR students can explore the repeatability of observations and variations in what-if scenarios. Such questions as "Is it the same parabola if we drop the ball from a greater height?" and "Is the parabola the same for the first bounce as the last bounce?" become natural and valuable extensions.
- The power of visualization lets students quickly associate the plotted list data with the physical properties and mathematical functions the data describes.

Other changes occur once the data from real-world events is collected. CBR lets your students explore underlying relationships both numerically and graphically.

Explore data graphically

Use automatically generated plots of distance, velocity, and acceleration with respect to time for explorations such as:

- What is the physical significance of the y-intercept? the x-intercept? the slope? the maximum? the minimum? the derivatives? the integrals?
- How do we recognize the function (linear, parabolic, etc.) represented by the plot?
- How would we model the data with a representative function? What is the significance of the various coefficients in the function (e.g., $AX^2 + BX + C$)?

Explore data numerically

Your students can employ statistical methods (mean, median, mode, standard deviation, etc.) appropriate for their level to explore the numeric data. When you exit the RANGER program, a prompt reminds you of the lists in which REALTIME=NO data for time, distance, velocity, and acceleration is stored.

CBR plots—connecting the physical world and mathematics

The plots created from the data collected by RANGER are a visual representation of the relationships between the physical and mathematical descriptions of motion. Students should be encouraged to recognize, analyze, and discuss the shape of the plot in both physical and mathematical terms. Additional dialog and discoveries are possible when functions are entered in the Y= editor and displayed with the data plots.

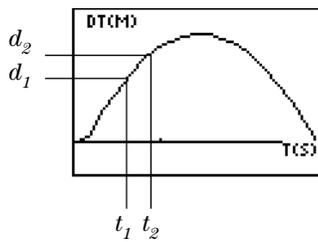
- A *Distance-Time plot* represents the approximate position of an object (distance from the CBR) at each instant in time when a sample is collected. y-axis units are meters or feet; x-axis units are seconds.
- A *Velocity-Time plot* represents the approximate speed of an object (relative to, and in the direction of, the CBR) at each sample time. y-axis units are meters/second or feet/second; x-axis units are seconds.
- An *Acceleration-Time plot* represents the approximate rate of change in speed of an object (relative to, and in the direction of, the CBR) at each sample time. y-axis units are meters/second² or feet/second²; x-axis units are seconds.
- The *first derivative* (instantaneous slope) at any point on the Distance-Time plot is the speed at that instant.
- The *first derivative* (instantaneous slope) at any point on the Velocity-Time plot is the acceleration at that instant. This is also the second derivative at any point on the Distance-Time plot.
- A *definite integral* (area between the plot and the x-axis between any two points) on the Velocity-Time plot equals the displacement (net distance traveled) by the object during that time interval.
- *Speed* and *velocity* are often used interchangeably. They are different, though related, properties. Speed is a *scalar* quantity; it has magnitude but no specified direction, as in “6 feet per second.” Velocity is a *vector* quantity; it has a specified direction as well as magnitude, as in “6 feet per second due North.”

A typical CBR Velocity-Time plot actually represents speed, not velocity. Only the magnitude (which can be positive, negative, or zero) is given. Direction is only implied. A positive velocity value indicates movement away from the CBR; a negative value indicates movement toward the CBR.

CBR measures distance only along a line from the detector. Thus, if an object is moving at an angle to the line, it only computes the component of velocity parallel to this line. For example, an object moving perpendicular to the line from the CBR shows zero velocity.

Teacher information (cont.)

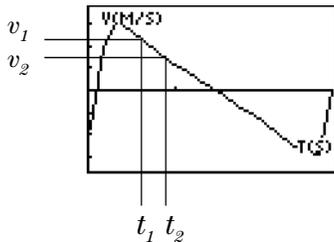
The mathematics of distance, velocity, and acceleration



Distance-Time plot

$$V_{\text{average}} = \frac{\Delta d}{\Delta t} = \frac{d_2 - d_1}{t_2 - t_1} = \text{slope of Distance-Time plot}$$

$$V_{\text{instantaneous}} = \lim_{\Delta t \rightarrow 0} \left(\frac{\Delta d}{\Delta t} \right) = \frac{d(s)}{dt} \quad \text{where } s = \text{distance}$$



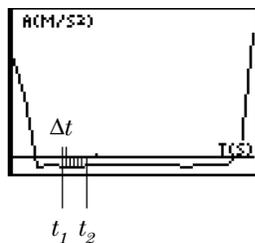
Velocity-Time plot

$$A_{\text{average}} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \text{slope of Velocity-Time plot}$$

$$A_{\text{instantaneous}} = \lim_{\Delta t \rightarrow 0} \left(\frac{\Delta v}{\Delta t} \right) = \frac{dv}{dt}$$

The area under the Velocity-Time plot from t_1 to $t_2 = \Delta d = (d_2 - d_1) =$ displacement from t_1 to t_2 (net distance traveled).

$$\text{So, } \Delta d = \left(\sum_{t=1}^{t=2} v(\Delta t) \right) \quad \text{or} \quad \Delta d = \int_{t=1}^{t=2} v(dt)$$



Acceleration-Time plot

Teacher information (cont.)

Web-site resources

At our web site, <http://www.ti.com/calc>, you'll find:

- a listing of supplemental material for use with CBR, CBL, and TI graphing calculators
- a library of programs for use with CBR, CBL, and TI graphing calculators
- an activities page with applications developed and shared by teachers like you
- CBR programs that access additional CBR features
- more detailed information about CBR settings and programming commands

Additional resources

Texas Instruments' *Explorations* books provide supplemental material related to TI graphing calculators, including books with classroom activities for CBR appropriate for middle-school and high-school math and science classes.

CBR data is stored in lists

Collected data is stored lists L1, L2, L3, and L4

When CBR collects data, it automatically transfers it to the calculator and stores the data in lists. Each time you exit the RANGER program, you are reminded of where the data is stored.

- L1 contains time data.
- L2 contains distance data.
- L3 contains velocity data.
- L4 contains acceleration data.

For example, the 5th element in list L1 represents the time when the 5th data point was collected, and the 5th element in list L2 represents the distance of the 5th data point.

In REALTIME=YES, only the data for the requested plot (distance, velocity, or acceleration) is calculated and transferred. In REALTIME=NO, all the data is calculated and transferred.

Settings are stored in list L5

The RANGER SETUP screen makes it easy to change the most commonly-used CBR parameters (see page 38).

When you transfer the RANGER program from the CBR, L5 is automatically replaced with a new list containing the defaults.

See pages 40–41 for information about programming commands that change other settings.

Using the data lists

The lists are not deleted when you exit the RANGER program. Thus, they are available for additional graphical, statistical, and numerical explorations and analyses.

You can plot the lists against each other, display them in the list editor, use regression analysis, and perform other analytical activities. For example, you could collect the data from pendulum motion using RANGER, exit RANGER, and then plot Velocity-Acceleration to explore elliptical functions. (You may also need to adjust the Window.)

RANGER settings

Changing RANGER settings

RANGER displays the most commonly used settings before data collection begins.

- 1 From the MAIN MENU in the RANGER program, choose SETUP/SAMPLE. The current settings are shown. ▶ indicates the location of the cursor.

MAIN MENU START NOW

REALTIME: → YES or NO
TIME (S): → TOTAL TIME = 1–99 SECONDS (REALTIME=NO only)
DISPLAY: → DISTANCE, VELOCITY, or ACCELERATION
BEGIN ON: → [ENTER], [TRIGGER], or 10-SECOND DELAY
SMOOTHING: → NONE, LIGHT, MEDIUM, or HEAVY
UNITS: → METERS or FEET

- 2 Press ▼ or ▲ to move to the setting you want to change.
- 3 Press [ENTER] to cycle through the available options. When the option is correct, press ▼ or ▲ to move to the next option. To change TIME, enter 1 or 2 digits, and then press ▼ or ▲.
- 4 When all the settings are correct, press ▼ or ▲ until the cursor is on START NOW.
 - To continue, press [ENTER].
 - To return to the MAIN MENU, press ◀, and then press [ENTER].

The new settings remain unless you choose SET DEFAULTS, run an application, or run another program that changes the settings. If you manipulate L5 outside the RANGER program or delete L5, the default settings may be restored the next time you run RANGER.

Restoring RANGER settings to the defaults

The default settings are appropriate for a wide variety of sampling situations. If you are unsure of the best settings, begin with the default settings, and then adjust.

- 1 From the MAIN MENU in the RANGER program, choose SET DEFAULTS.

The settings are changed to the defaults and the SETUP screen is displayed.
- 2 If you wish to change a setting from the default, follow the steps above.
- 3 To continue, press [ENTER] when cursor is on START NOW.

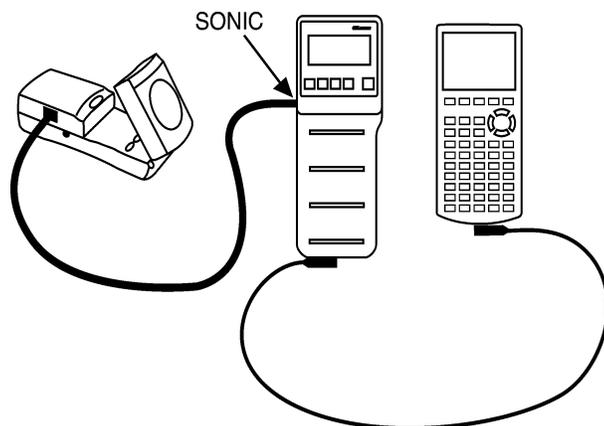
Other RANGER settings

The RANGER program accesses the most commonly changed settings. CBR has additional settings. See pages 40–41 for information about programming commands that change these settings.

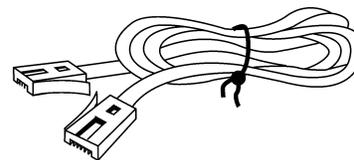
Using CBR with CBL or with CBL programs

Using CBR as a conventional motion detector with CBL

The CBR can be used as a conventional motion detector with the Texas Instruments CBL™ (Calculator-Based Laboratory™) system.



A special cable is required to connect the CBR to CBL.



You may order the cable by calling 1-800-TI-CARES.

Do not connect CBR to CBL at the same time that CBR is connected to a calculator. The calculator must be connected to CBL.

You may need to change the CBL program as noted below. The RANGER program does not function with CBL.

Using CBR with programs written for CBL

You can use CBR with most CBL programs written for only a motion detector with no changes or only minor changes to the program.

To stop sampling: With some CBL programs using REALTIME=YES data collection, CBR continues to sample indefinitely. To stop data collection at the end of the sample time, you can do either of the following:

- Press **TRIGGER** on the CBR.
- Add statements to the existing CBL program to send the command {6,0} to the CBR. The statement must be at a point after the data is transferred and displayed. For example:

```
{6,0}→L6:SEND L6
```

To turn sound off or on: To turn off the sound, add statements to the existing CBL program to send the command {6,3} to the CBR. The statement must be at a point before data collection begins. For example:

```
{6,3}→L6:SEND L6
```

To turn on the sound, simply run the RANGER program.

In case of difficulty: If you run a CBL program and CBR appears to be unresponsive or locked up, run the RANGER program. Check the TI web site (see page 36), which may have an updated version of the CBL program.

Programming commands

Command 0	Clears and resets system	{0}
	Clears all. Resets power-on defaults. Channel 11 automatically selected.	
Command 1	Clears channels	{1,0}
	Clears channel settings; does not clear errors	
Command 1	Channel	{1,11,operation,post_processing,0,temperature_conversion}
<i>operation</i>		Results
0	(REALTIME=NO)	Clears all. Resets power-on defaults.
1	(REALTIME=NO)	Meters
2	(REALTIME=NO)	Meters
3	(REALTIME=NO)	Feet
<i>operation</i>		Results
0	(REALTIME=YES)	Clears all. Resets power-on defaults.
1	(REALTIME=YES)	Meters CBR returns { <i>distance,Δtime</i> }
2	(REALTIME=YES)	Meters CBR returns { <i>distance,Δtime</i> }
3	(REALTIME=YES)	Feet CBR returns { <i>distance,Δtime</i> }
4	(REALTIME=YES)	Meters CBR returns { <i>distance,velocity,Δtime</i> }
5	(REALTIME=YES)	Feet CBR returns { <i>distance,velocity,Δtime</i> }
6	(REALTIME=YES)	Meters CBR returns { <i>distance,velocity,acceleration,Δtime</i> }
7	(REALTIME=YES)	Feet CBR returns { <i>distance,velocity,acceleration,Δtime</i> }
<i>post_processing</i>		Results
0	(default)	None
1	(REALTIME=NO)	d/dt (1st-order derivative)
2	(REALTIME=NO)	d ² /dt ² (2nd-order derivative)
<i>temperature_conversion</i>		Results
0	(default)	Disables temperature compensation.
1		Enables temperature compensation.
Command 2	Data setup	{2,data_type,0,0,0,0,0,0}
<i>data_type</i>		Results
1	(default)	List
Command 3	Sample/Trigger	{3,sample_time,sample#,trigger,0,0,0,record_time,filter}
<i>sample_time</i>		Results
0.005–1500 (0.1)		Time in seconds between each sample
0.0001–0.005		Rounds to 0.005.
1500<x<16000		Rounds to 1500.
<i>sample#</i>		Results
-1		Selects REALTIME=YES data collection mode.
1–512 (REALTIME=NO)		Takes from 1 to 512 samples.
<i>trigger</i>		Results
0		Begins sampling with no trigger.
1 (default)		Begins sampling on TRIGGER .
7		Delays 10 seconds, then begins sampling.
<i>record_time</i>		Results
0 (default)		None
1 (REALTIME=NO)		Absolute time (starts at time 0, then adjusts sample time)
2 (REALTIME=NO)		Relative time (starts at time 0, then adjusts sample time)
<i>filter</i> (see command 1, operation field)		Results
0 (default)		No filtering
1 (REALTIME=NO)		5 point Savitzsky-Golay smoothing
2 (REALTIME=NO)		9 point Savitzsky-Golay smoothing
3 (REALTIME=NO)		17 point Savitzsky-Golay smoothing
4 (REALTIME=NO)		29 point Savitzsky-Golay smoothing
5 (REALTIME=NO)		3 point median pruning filter
6 (REALTIME=NO)		5 point median pruning filter
7 (REALTIME=YES)		Light REALTIME=YES tracking filter
8 (REALTIME=YES)		Medium REALTIME=YES tracking filter
9 (REALTIME=YES)		Heavy REALTIME=YES tracking filter

Programming commands (cont.)

Command 4 Temperature compensation	{4, <i>equation#</i>, <i>equation_type</i>, <i>temperature</i>, <i>units</i>}
<p><i>equation#</i> 0 (default) 4</p> <p><i>equation_type</i> 0 (default) 13</p> <p><i>temperature</i> floating-point number</p> <p><i>units</i> 0 (default) 1 2 3 4</p>	<p>Results Clears all equations. Designates equation 4.</p> <p>Results Clears equation. Designates temperature compensation.</p> <p>Results Sets current temperature.</p> <p>Results None (ignored by CBR). Sets T degrees to Celsius. Sets degrees = Fahrenheit. Sets degrees = Celsius. Sets degrees = Kelvin. Sets degrees = Rankin where $R = F + 459.7$.</p>
Command 5 (REALTIME=NO) Data range setup	{5, <i>first_channel</i>, <i>data_select</i>, <i>data_begin</i>, <i>data_end</i>}
<p><i>first_channel</i> 0 (default) 1, 2, 3, 11, 21 -1</p> <p><i>data_select</i> 0 1 2 3 4 5</p> <p><i>data_begin</i> 1–512</p> <p><i>data_end</i> 0–512</p>	<p>Results Selects lowest active channel. Specifies sonic channel. Records time list.</p> <p>Results Smoothed data {distance} Smoothed d/dt data {velocity} Smoothed d²/dt² data {acceleration} Raw data {distance} Raw d/dt data {velocity} Raw d²/dt² data {acceleration}</p> <p>Results First data element for GET</p> <p>Results Last data element for GET (0 = last sample)</p>
Command 6 Systems options	{6, <i>system_command</i>[, <i>operation</i>]}
<p><i>system_command</i> 0 2 (default) 3 4 5 6</p> <p><i>operation</i> floating-point number 0–6</p>	<p>Results Stops sampling (for CBL compatibility). Stops sampling. Turns sound off (sound is on at power on). Turns sound on (sound is on at power on). Sets ID Number (<i>operation</i> required). Applies new filter to previous data (<i>operation</i> required).</p> <p>Results ID_Number of form <i>n.nnnnn</i> (<i>system_command</i> = 5) New filter for previously collected data (<i>system_command</i> = 6)</p>
Command 7 Request status	{7}
<p>Returns a list containing:</p> <p>10.rrrr 0–99 0–2 11 sample_time trigger_condition function post_processing filter samples recorded_time temperature piezo_flag system_state window_start window_end id_number</p>	<p>DeviceCode.RomVersion Last error code (0 = no error) Battery condition (0 = OK; 1 = low during samples; 2 = always low) Sonic-channel identifier Current sample interval in seconds Current triggering option in use Current channel function (1–9) Current post-processing option (0–2) Current filtering level (0–9) # of samples available; 0–512 REALTIME=NO; -1 REALTIME=YES Recorded time option (0–2) Temperature in use (°C) 0 = sound off; 1 = sound on 1 = not setup; 2 = armed; 3 = triggered/sampling; 4 = done 0 = no command 5 yet; 1–512 0 = use # of elements; 1–512 6 digit ID # (default 0.00000) set by command 6 (<i>system_command</i> = 5)</p>

Batteries

Battery type

CBR is designed to operate with 4 AA alkaline batteries. CBR can run without batteries only if attached to a CBL.

Battery installation

Exit the RANGER program before changing batteries.

Holding the CBR upside down, use your thumb to slide the battery compartment cover toward the back of the CBR. Position batteries according to the diagram on the inside of the CBR battery compartment. Two batteries fit positive side up in the side marked +. Two batteries fit negative side up in the side marked -. Slide the cover back on. CBR is ready to begin sampling.

CBR low battery warnings

CBR has two mechanisms to alert you that the batteries are low:

- The RANGER program displays a warning message on calculator screen while trying to collect data.
- The red light flashes intermittently while the CBR is collecting sample data.

CBR battery power status

You can check the battery power before you begin sampling. From the MAIN MENU choose TOOLS, and then choose CBR STATUS. The battery status, OK or REPLACE, is shown.

Battery precautions

- Replace all four batteries at the same time. Do not mix brands of batteries. Do not mix types within a battery brand.
- Install batteries according to the diagrams inside the battery compartment.
- Properly dispose of used batteries immediately. Do not leave them within the reach of children.
- Do not heat, burn, or puncture batteries. Batteries contain hazardous chemicals and may explode or leak.
- Do not mix rechargeable and nonrechargeable batteries.
- Do not place nonrechargeable batteries in a battery recharger.

In case of difficulty

<i>If you have this problem:</i>	<i>Try this:</i>
Difficulty transferring the RANGER program or collecting data	<p>Check for a poor calculator-to-CBR connection. Always push in firmly on both ends of the cable.</p> <p>Check for low batteries (see page 42).</p>
CBR begins collecting data by itself	<p>If you set down the CBR with the TRIGGER button face down, the TRIGGER button may depress and activate sampling. Press TRIGGER again to stop sampling.</p> <p>Before storing the CBR, properly exit the RANGER program (using QUIT) or any other CBR or CBL program.</p>
CBR doesn't quit collecting data	<p>Press TRIGGER to stop sampling. Repeat sample. If problem continues, check program code.</p>
LINK ERROR message	<p>Attach the CBR to the calculator with the calculator-to-CBR cable.</p> <p>Check for a poor calculator-to-CBR connection. Always push in firmly on both ends of the cable.</p> <p>If you do not want to (or cannot) attach the CBR to the calculator, press ON to break out of the program, and then choose QUIT.</p>
Insufficient memory	<p>You must have sufficient memory for the RANGER program and the data lists. The programs and lists require approximately 17,500 bytes. Delete programs and/or data.</p>
Calculator doesn't match activity instructions	<p>This guide applies to all the TI calculators that can be used with CBR, so you may find that some of the menu names, screens, or keys in this guide do not match exactly those on your calculator. Choose the closest match. For example, if the instructions say "Choose DISTANCE MATCH," on the TI-83 you would choose DIST MATCH.</p>
Data doesn't look right: <ul style="list-style-type: none"> ■ points not on the curve ■ jagged plots ■ flat plots ■ broken plot 	<p>Repeat the sample, ensuring that the CBR is aimed directly at the object.</p> <p>Read pages 6–12 on getting good data samples.</p> <p>Check that the <i>clear zone</i> does not contain students, tables, or other objects.</p> <p>When using two CBR units at the same time in the same room, one group should complete a sample before the next group begins their sample.</p> <p>Check for a poor calculator-to-CBR connection. Always push in firmly on both ends of the cable.</p> <p>Check for low batteries (see page 42).</p> <p>Check that the degree of smoothing is not too much or too little.</p>
CBR won't work with a TI-85	<p>Check to see that "CBL" appears at the end of the serial number on the back of the calculator to indicate compatibility with CBL and CBR.</p> <p>The TI-85 does not have statistical plotting capabilities, so some explorations (such as using TRACE on plotted data) are not possible on the TI-85.</p>
Lost calculator-to-CBR cable	<p>You can use the calculator-to-calculator cable that came with the calculator. (The calculator-to-calculator cable is much shorter, so you may wish to order a replacement cable.)</p>
Frequently low batteries	<p>Before storing the CBR, properly exit the RANGER program (using QUIT) or any other CBR or CBL program, and disconnect CBR from the calculator.</p>
When you try to run the RANGER program, nothing happens	<p>If you edit or view the RANGER program, the next time you run it, it may take up to two minutes for the calculator to prepare the program to run. This is normal.</p>
Error message: Variable is locked or protected (TI-92 only)	<p>You must unlock the variables L1, L2, L3, L4, and L5. See the calculator manual.</p>

TI service and warranty

For US Customers Only

For general questions

Call Texas Instruments Customer Support:
1-800-TI-CARES (1-800-842-2737)

For technical questions

Call the Programming Assistance Group of Customer Support:
1-972-917-8324

For service information

Always contact Texas Instruments Customer Support before returning a product for service.

Customer support hours

8:00^{AM}–4:30^{PM} CST on Monday–Thursday and 9:30^{AM}–4:30^{PM} CST on Friday.

For more information about TI products and services, contact TI by e-mail or visit the TI calculator home page on the World Wide Web.

ti-cares@ti.com
<http://www.ti.com/calc>

TI one-year limited warranty

This Texas Instruments electronic product warranty extends only to the original purchaser and user of the product.

Warranty Duration. This product is warranted to the original consumer purchaser for a period of one (1) year from the original purchase date.

Warranty Coverage. This Texas Instruments electronic product is warranted against defective materials and construction. **This warranty is void if the product has been damaged by accident or unreasonable use, neglect, improper service, or other causes not arising out of defects in materials or construction.**

Warranty Disclaimers. Any implied warranties arising out of this sale, including but not limited to the implied warranties of merchantability and fitness for a particular purpose, are limited in duration to the above one-year period. Texas Instruments shall not be liable for loss of use of the product or other incidental or consequential costs, expenses, or damages incurred by the consumer or any other user.

Some states/provinces do not allow the exclusion or limitation of implied warranties or consequential damages, so the above limitations or exclusions may not apply to you.

Legal Remedies. This warranty gives you specific legal rights, and you may also have other rights that vary from state to state or province to province.

Warranty Performance. During the above one (1) year warranty period, your defective product will be either repaired or replaced with a reconditioned model of an equivalent quality (at TI's option) when the product is returned, postage prepaid, to Texas Instruments Service Facility. The warranty of the repaired or replacement unit will continue for the warranty of the original unit or six (6) months, whichever is longer. Other than the postage requirement, no charge will be made for such repair and/or replacement. TI strongly recommends that you insure the product for value prior to mailing.

FCC information concerning radio frequency interference

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference with radio communications. However, there is no guarantee that interference will not occur in a particular installation.

If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, you can try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/television technician for help.

Caution: Any changes or modifications to this equipment not expressly approved by Texas Instruments may void your authority to operate the equipment.

RANGER MAIN MENU

SETUP / SAMPLE

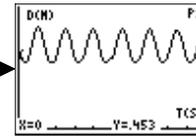
```

MAIN MENU  ▶START NOW
REALTIME:  . . . . .
TIME (S):  . . . . .
DISPLAY:   . . . . .
BEGIN ON:  . . . . .
SMOOTHING: . . . . .
UNITS:     . . . . .
    
```

SET DEFAULTS

```

MAIN MENU  ▶START NOW
REALTIME:  YES
TIME (S):  15
DISPLAY:   DIST
BEGIN ON:  [ENTER]
SMOOTHING: NONE
UNITS:     METERS
    
```



NO
YES

1-99
(REALTIME=NO)

DISTANCE
VELOCITY
ACCELERATION

[ENTER]
[TRIGGER]
DELAY

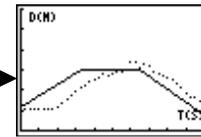
NONE
LIGHT
MEDIUM
HEAVY

METERS
FEET

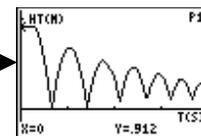
APPLICATIONS

UNITS
METERS
FEET

APPLICATIONS
DISTANCE MATCH
VELOCITY MATCH
BALL BOUNCE
MAIN MENU



OPTIONS
SAME MATCH
NEW MATCH
APPLICATIONS
MAIN MENU
QUIT



PLOT MENU

REALTIME=NO

```

DISTANCE-TIME
VELOCITY-TIME
ACCELERATION-TIME
PLOT TOOLS
REPEAT SAMPLE
MAIN MENU
QUIT
    
```

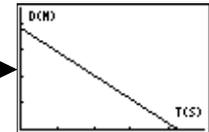
REALTIME=YES

```

SHOW PLOT
SELECT DOMAIN
REPEAT SAMPLE
MAIN MENU
QUIT
    
```

PLOT TOOLS
SELECT DOMAIN
SMOOTH DATA
PLOT MENU

DATA SMOOTHING
LIGHT
MEDIUM
HEAVY
NONE



TOOLS

TOOLS
GET CBR DATA
GET CALC DATA
CBR STATUS
STOP/CLEAR CBR
MAIN MENU

QUIT