

**Title: Slip Slide'n Away**

An interdisciplinary lesson on friction adapted from "Activity 11: Coefficients of Friction," Exploring Physics and Math with the CBL System, Texas Instruments Incorporated, 1994.

**Link to Outcomes:**

- **Problem Solving** Students will apply a mathematical model to a problem involving sliding boxes across a warehouse floor.
- **Communication** Students will express their ideas orally and in writing.
- **Reasoning** Students will make a conjecture about the problem solution and test its validity.
- **Connections** Students will use and value the connections between math and science present in this problem.
- **Algebra** Students will use algebra to represent the real-life data with a variable expression. They will also interpret the equation using a graph.
- **Functions** Students will model real-world phenomena using a linear function and will represent this function with both an equation and a graph.
- **Statistics** Students will use graphs and curve fitting to analyze data.
- **Technology** Students will demonstrate their ability to collect and analyze data using available technology.

**Brief Overview:**

This is a lesson in which the math student collects real data related to friction. The resulting mathematical analysis allows them to plot data points and find the equation of the graph. The lesson also includes a discussion on the type of graph, its slope, and its physical meaning.

**Grade/Level:**

Grades 9-12/Algebra 1, Algebra 2, Physics, Pre-calculus

**Duration/Length:**

This lesson is expected to take two 45-minute class periods. With the extensions, it may take one extra class period.

### **Prerequisite Knowledge:**

Students should be familiar with basic equations of lines and with graphing on the coordinate plane. Teacher should be familiar with both the Calculator Based Laboratory (CBL) and the Texas Instrument Graphics Calculator (TI-82). If students have no experience with graphing calculators, the lesson may take longer than two class periods.

### **Objectives:**

- Observe frictional forces associated with sliding objects of different weights and materials.
- Use CBL to collect data.
- Use TI-82 to analyze data.
- Use TI-82 GraphLink to transfer graph results.
- Interpret results and draw conclusions.
- Express answers clearly in writing.

### **Materials/Resources/Printed Materials:**

- CBL Unit, 1 per group
- TI-82 Graphing Calculator, 1 for each pair of students
- Unit to Unit Link cables (one for each CBL)
- Vernier student force sensor (SFS-DIN) with CBL-DIN adapter, one for each CBL
- Programs CBL and FORCECERT (Teacher Resource #2) both loaded into each calculator through the GRAPHLINK or by hand. Programs are taken from Exploring Physics and Math with the CBL System, 1994.
- Optional computer and printer with GRAPHLINK to print student graphs
- Worksheets (Student Resource #1-4), one copy per student
- For each group:
  - one block of wood with a fairly rough surface **or** with aluminum foil taped to the bottom (With advanced classes, use rough on one side, aluminum on the other. Be sure to evenly distribute types of carriers through class for final comparison.)
  - one set of various weights with approximately six combinations possible (Force probe can measure a maximum of 20 N or approximately 2 kg.)
  - string attached to each carrier

### **Development/Procedures:**

Students will be asked to conjecture as to which would be the most efficient option for moving a very heavy load across a warehouse. Would we use a carrier with a metal or wooden base?

Using available technology, assign students to groups, preferably four students in each. Assign the following roles within the group: one student to run the CBL, one student to control the TI-82, one student to record data, and one student to operate the force probe.

Ask students to gather equipment and set up the CBL System using the force probe. Follow the Technology Set Up Procedure. Half of the groups will use wooden carriers and the others, metal. (Advanced classes use carriers with metal on one side, wood on the other.)

Instruct students to gather data according to the Experiment Procedure Sheet. Students will execute the CBL menu program as instructed and will obtain a graph of Force vs. Time. They will then use a horizontal line, to find the force exerted for constant velocity. If their graph is not a horizontal line, they will need to repeat that step. The y-value of this horizontal line is the value (force in Newtons) that should be placed in the data chart, along with the weight in Newtons of what they pulled during that trial. The students should have the table at the end of Student Resource #2 completed by the end of the first class period.

Explain the “Using Statistical Functions on the TI-82” worksheet (Student Resource #3) to students and have them enter their data from the experiment and find the line of best fit. They should also print out both the graph and equation on the computer if GRAPHLINK is available. Otherwise, the students should sketch the graph and copy the equation onto graph paper.

Each group should present results to the class, preferably on the overhead. The class should then make a decision about the best surface to be used in the warehouse. Lead a class discussion on the relationship between the force of friction and the weight of an object being pulled (they vary *directly*). The discussion should also include the coefficient of friction, and the general equation

$$F = \mu N,$$

where  $F$  is the frictional force,  $\mu$  is the coefficient of friction, and  $N$  is the normal weight of the object pulled. If the surfaces remain the same, the coefficient of friction,  $\mu$ , will be constant without regard to the weight of the object pulled.

### **Evaluation:**

Students will be evaluated using classroom observation as well as completion of the questions on the Experiment Procedure Sheet (Student Resource #2) and the graph of the data and line of best fit. There will also be a follow-up worksheet (Student Resource #4) to be completed for homework.

### **Extension/Follow Up:**

This lab could be extended to include an incline plane and a comparison of the same surfaces both level and at several angles of inclination.

“Curling” Task Sheet, Modeling with force and motion, Cambridge University Press 1992, pp. 54-56 is an activity that examines the “model of friction...for a curling stone traveling along the ice.” This would be appropriate for Physics or higher level mathematics students.

For Algebra 1 students, an activity on slope would easily follow after this lesson.

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## **Slip Slide'n Away–Day 1 Technology Set Up Procedure**

### **Materials:**

- CBL Unit, one per group
- TI-82 Graphics Calculator, one for each pair of students
- Unit to Unit Link cables (one for each CBL)
- Vernier student force sensor (SFS-DIN) with CBL-DIN adapter, one for each CBL
- Worksheets (Student Resource #1-4), one copy per student
- For each group:
  - one carrier, either metal or wood (both for advanced classes)
  - a set of various weights with at least 6 combinations possible (force probe can measure a maximum of 20 N or approximately 2 kg.)
  - string attached to each carrier

### **Procedure:**

The TI-82 should have programs already loaded on it by the teacher.

1. Link the TI-82 to the CBL using the unit to unit link cables and the ports on the bottom edge of each.
2. Link the force probe, with CBL-DIN adapter, to the CBL. The CH1 port is located on the top edge of the CBL.
3. Make sure cables are firmly pressed into the ports.
4. Turn on the TI-82.
5. Press {pr gm}; use {G} to go to <CBL>; {eNter }; {eNter }
6. Use {G} to select <FORCE>; {eNter }
7. Use {G} to select <FORCE(RLTIME)>; {eNter }
8. Use {G} to select <AUTO>; {eNter }
9. Turn on the CBL
10. Remove all forces from the probe, and press {eNter } to zero it.

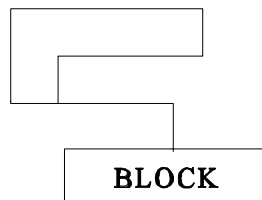
You are now ready to continue with the Experiment Procedure Sheet.

**Slip Slide'n Away--Day 1  
Experiment Procedure Sheet**

The problem: Which would be the most efficient option for moving a very heavy load across a warehouse? Would one use a carrier with a metal or wooden base?

**\*\*\*\*\*What do you think? Talk with your group and put your answer here. \_\_\_\_\_**

Attach the force probe to the carrier using a piece of string. Hold the probe as shown. It is important that the force be exerted perpendicular to the handle of the probe. Check the diagram below. Then press {eNter}.



A graph of the data collected will be plotted on the TI-82 display. Press {2ND} <DRAW> {3} to display a horizontal line on the screen. Use the arrow keys to move up or down until the horizontal line aligns with the portion of the data curve that is horizontal. The displayed y-value represents the weight of the object. Record the y-value in the chart provided below. Round to two decimal places.

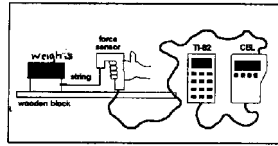
Carrier Number    Weight

|  |  |
|--|--|
|  |  |
|--|--|

For Trial 1, use an empty carrier. Add weight to make the carrier heavier each trial (Be sure to include the empty carrier and all weights added when putting the data in the chart).

| TRIAL | WEIGHT PULLED (N) | FORCE TO PULL (N) | FORCE/WEIGHT |
|-------|-------------------|-------------------|--------------|
| 1     |                   |                   |              |
| 2     |                   |                   |              |
| 3     |                   |                   |              |
| 4     |                   |                   |              |
| 5     |                   |                   |              |
| 6     |                   |                   |              |

Collect data on the force needed to pull these carriers by holding the probe as indicated in the diagram.



Keep the string parallel to the table, and try to pull at a steady rate so that it moves with a constant velocity. This should make a horizontal line on the graph. Between each trial press {clear}, {clear}, {eNter}, {4}, {2}, {1}. Use {2ND} {Dr aw} {3} and the arrow keys to get a horizontal line that matches the graph. Find the  $y$ -value that represents the force and record the data in the chart on the previous page.

### Observations and Conclusions

1. What do you notice about the amount of force needed to pull the carrier as the weight was increased?
2. Mathematically, we can say that these quantities vary \_\_\_\_\_.
3. What quantity was graphed on the  $x$ -axis?
4. What quantity was graphed on the  $y$ -axis?
5. Why was it important for the graph to be a horizontal line?
6. What occurrence explains the points that do not lie on the horizontal line?
7. Observe the column of force/weight data.
  - a. What do you notice?
  - b. What do you think this means?
  - c. Why is this data without units?

## Slip Slide'n Away–Day 2

**Using Statistical Functions on the TI-82**  
**NSA SUMMER INSTITUTE MATHEMATICS NOTEBOOK, 1994**

**Entering the data:**

1. Clear all previous data

Press {stat}; press {4} and then press {2ND} <L<sub>1</sub>> , {2ND} <L<sub>2</sub>> {eNter}  
 (This should clear all of the data in these two lists.)

2. To enter edit mode

Press {stat} and press {1} (to select Edit).

3. Entering the data

Type in the first value of  $x$  (WEIGHT) in the L<sub>1</sub> position. Press {eNter}. This will set up to enter the next  $x$  value. Using the {H} key will allow one to enter the corresponding  $y$  (FORCE) values.

4. To get back to the main screen,

Press {2ND} <Quit>.

**Graphing the data:**

1. Turn off all currently operating graphs

Press {2ND} <STAT PLOT>. Press {4} and {eNter}.

2. To enter statistical graphing mode and set up parameters

Press {2ND} <STAT PLOT>. Press {1} . Page down through the selection using the {G} key. Change the screen so that the following selections are highlighted.

ON  
 Type: Scatter  
 Xlist: L<sub>1</sub>  
 Ylist: L<sub>2</sub>  
 Mark:

[Note: When simultaneously graphing, one may choose to use different marks.]



3. To graph the data

Press {ZOOM} {9}.

This command automatically adjusts the window for statistical data.

**Line of best fit:** When calculating the line of best fit, it is important to evaluate the correct data lists. To verify this, you can check the 2-Var Stats under the SetUp command by pressing {stat} and {H} to **Calc**.

**Linear equations**  $y = ax + b$

- A. Calculate the equation for the regression line  
Press {stat}. Press {H} to **Calc**. Use the {G} to get to 5 and press {eNter} twice.
- B. Setting up the equation in the Y= editor  
Press {y=}. The following steps will allow one to set up the actual equation. Press {vars}. Press {5}. Press the {H} twice to get to EQ. Press {7}.
- C. Graphing the regression equation on the data  
Press {graph}.

### **Results and Conclusions:**

Either print your graph and equation using GraphLink for the TI-82 with teacher assistance or put the graph obtained onto graph paper.

Prepare to present the results to the class. Be sure to include the type of carrier used in the explanation of the data.

A class discussion will follow. Take notes carefully, and compare results to those of other groups. The equations discussed are necessary for your homework.

**\*\*\*\*Which type of carrier would you use if you were in charge of the warehouse?**

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**Slip Slide'n Away–Day 2  
Homework Worksheet**

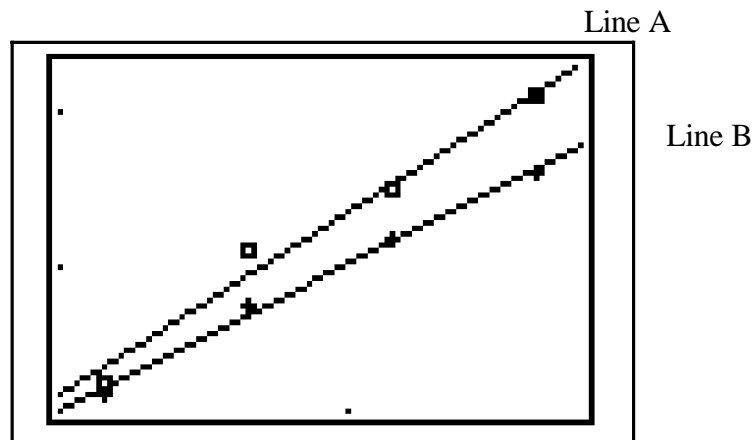
1. From the activity in class, what equation relates the weight of an object to the force necessary to slide it across a surface?
  
2. If pushing an object from left to right, in which direction would the force of friction act?
  
3. In the following pairs, which would have the greater coefficient of friction?
  - a. brick and wood
  - b. cardboard and sandpaper
  - c. tile and carpet
  - d. rubber and glass
  - e. wet road surface and dry road surface
  
4. Why is rubber used for car tires?

[Problems 5-7 are from the book Modeling With Force And Motion, Cambridge University Press, 1992.]

5. A block of weight 60N will move at constant velocity when pushed along a table by a horizontal force of 24N. Find the coefficient of friction between the block and the table.
  
6. An ice hockey puck of weight 1N is sliding in a straight line on an ice rink. The coefficient of sliding friction between the puck and the ice is 0.02. Find the resistive force due to friction.

7. Your gym teacher asks you to move a box of heavy equipment across the gym floor. How much does it weigh if the coefficient of friction is 0.1 and the force you apply to move it is 150N?

This is an example of experimented results similar to that done in class for this activity. Consider the following graph to answer questions 8-11.



8. What quantity was graphed on the  $x$ -axis in lab?
9. What quantity was graphed on the  $y$ -axis in lab?
10. Which line, A or B, would represent a wooden-based object sliding across the floor?
11. Which line, A or B, would have the lowest coefficient of friction?

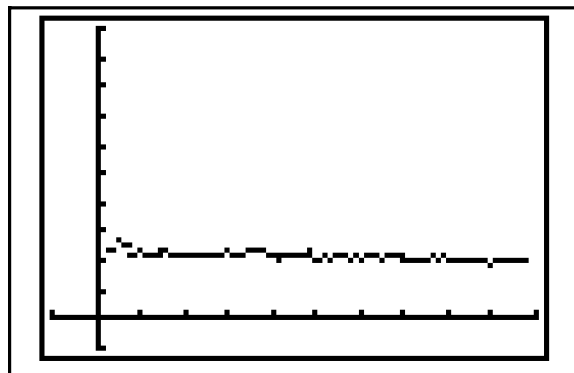
## Slip Slide'n Away Guideline for Teacher

### Suggestions for Day 1 Activities

1. Make sure that both programs, CBL and FORCERT, are stored in each TI-82. This can be done using the unit to unit link. The programs can be imported using the GraphLink or can be typed in using the copies in this unit.
2. The ideal carrier would be made from a 2X4 block of wood with one rough side with aluminum foil taped on the other side. The block would need a hook to attach string. This would extend to the later discussion that the only difference in the carrier is surface.
3. Label each carrier for identification by groups. Before the lesson, label all weights in Newtons with masking tape. Each group needs six total combinations of weights. A digital scale (available in science departments) is ideal for this job. Weight in Newtons = mass(kg) X  $9.8\text{m/s}^2$ .
4. Emphasize the problem at the top of the Experiment Procedure Sheet (Student Resource #2). Encourage students to discuss their answers with their group before writing them down, and ask that they have a reason to back up their choices.
5. In a more advanced class, each group could collect data for both wood and metal by dividing the last two columns in the chart in half. It will be necessary to revise Day 2 instructions for entering two data sets and finding two lines of best fit.

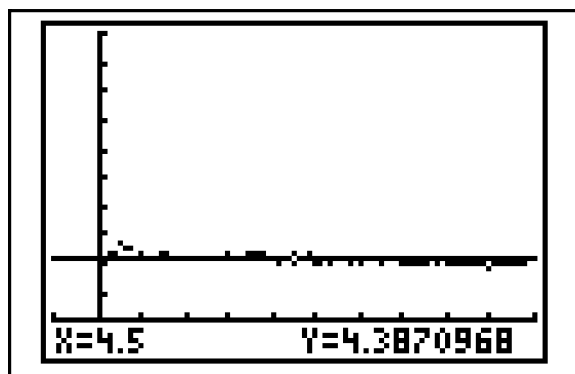
[Hint:  $L_1$ : Weight pulled  
 $L_2$ : Force used for wood side  
 $L_3$ : Force used for foil side  
 Use Statplot 1 and 2  
 Use LinReg  $L_1, L_2 \rightarrow Y_1$   
 LinReg  $L_1, L_3 \rightarrow Y_2$ ]

6. In collecting the data, it is important that the student pulling the block across the table use a constant velocity so that the force will be constant. This will show up as a horizontal line on the graph. If the student's graph is not horizontal, he may need to retry that weight. Below is an example of a fairly accurate horizontal graph.



*Weight pulled at fairly constant velocity.*

7. After using the draw function, students will then decide on the force used to move the carrier. This is an approximation. Below is an example of the appropriate horizontal line for the graph on the previous page.



The students would record the force for this graph as 4.39N.

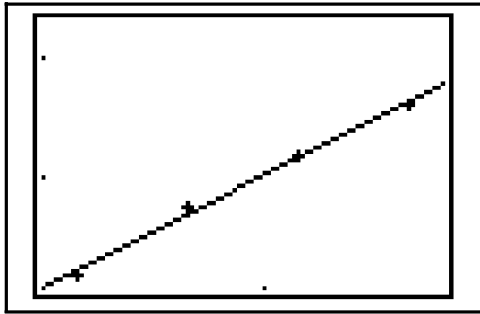
#### Solutions to Day 1 Experiment Procedure Sheet, Observations and Conclusions

1. The amount of force needed increases as the weight increases.
2. Directly
3. Time was the quantity on the  $x$ -axis.
4. Force was the quantity on the  $y$ -axis.
5. This represents where the velocity is constant; therefore, the friction force is equal to the pulling force measured.
6. The points not in a line represent either acceleration (speeding up) or deceleration (slowing down).
7. The values are about the same, especially when examined to one decimal place. This means that the ratio of force/weight represents the coefficient of friction for the surface. It is an indicator of how rough or smooth is the surface. Low coefficients indicate ease in motion. This is why we use lubricants. Both force and weight are measured in Newtons; therefore, the units cancel in the ratio.

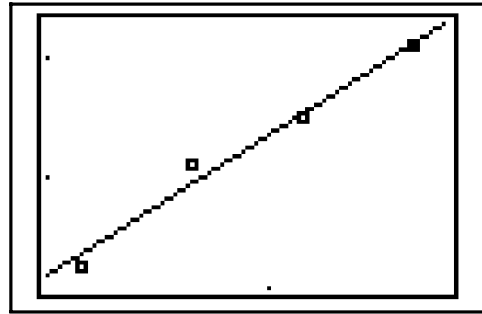
#### Suggestions for Day 2 Activities

1. After students find the linear regression, they should either print graphs with GraphLink or sketch graphs on graph paper using original data sets. Request them either to print or to copy their regression equations. These will be used in their presentations to the class.

2. Below are two examples of linear regressions.

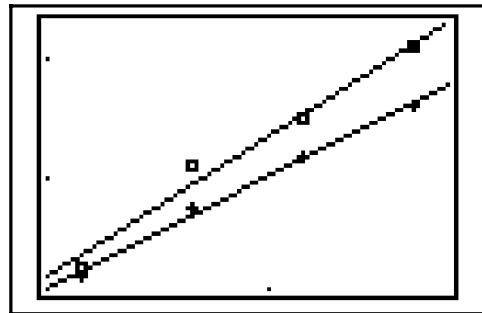
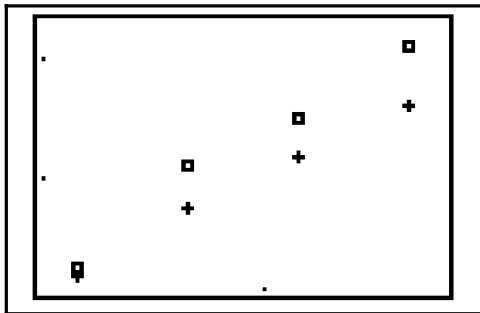


**Metal carrier**



**Wood carrier**

3. Below are examples of both sets of data on one graph and both linear regressions on one graph to be used for advanced groups or teacher demonstration.



4. Below is the TI-82 screen of regression equations for the above lines.

```

Y1 = .210360360360
36X + -.0419009009
000
Y2 = .261486486486
49X + .10228378378
375
Y3 =
Y4 =
    
```

In this case, .21 and .26 represent the slope of the line which is the coefficient of friction for each block.

Solutions to Day 2 homework worksheet

1.  $F = \mu N$  where  $F$  is force of friction,  $\mu$  is coefficient of friction, and  $N$  is normal force (weight).
2. Friction opposes motion; therefore, the force of friction here would be right to left.
3.
  - a. brick
  - b. sandpaper
  - c. carpet
  - d. rubber
  - e. dry road surface
4. Rubber tires allow better friction for traction, handling, and stopping.
5.
$$24N = \mu(60N)$$
$$24/60 = \mu$$
$$.4 = \mu$$
6.
$$F = .02(1N)$$
$$F = .02N$$
7.
$$150N = .1(N)$$
$$150/.1 = N$$
$$1500N = N$$
8. Weight (normal force)
9. Force of friction  
\*Since force/weight =  $\mu$ , then  $\mu$  is the slope.
10. Line A
11. Line B

**TI-82 Programs for the CBL**  
**Exploring Physics and Math with the CBL System, 1994**

**Program: CBL**

```

:Lbl 0
:ClrHome
:Menu("CBL MAIN MENU","MOTION",B,"TEMPERATURE",E,
      "SOUND",A,"FORCE",C,"PLOTS",F,"QUIT",Z)
:Lbl A
:prgmSOUND
:Stop
:Lbl B
:Menu("***MOTION MENU**","MOTION",1,"DISTANCE-RT",2,"D-T
      MATCH",3,"BOUNCING BALL",4,"QUIT",0)
:Lbl 1
:prgmMOTION
:Stop
:Lbl 2
:prgmMOTIONRT
:Stop
:Lbl 3
:prgmDTMATCH
:Stop
:Lbl 4
:prgmBOUNCE
:Stop
:Lbl C
:Menu("***FORCE MENU***","FORCE",7,"FORCE(RLTIME)",6,"SECOND
      LAW",9,"THIRD LAW",W,"FORCE TABLE",8,"QUIT",0)
:Lbl 9
:prgmSECOND
:Stop
:Lbl 8
:prgmFTABLE
:Stop
:Lbl W
:prgmTHIRD
:Stop
:Lbl 7
:prgmFORCE
:Stop
:Lbl 6
:prgmFORCERT
:Stop
:Goto 0
:Lbl E

```



```
:prgmTEMP
:Goto 0
:Lbl F
:prgmPLOTS
:Goto 0
:Lbl Z
:ClrHome
```

**Program Name:      FORCERT**

```
:PlotsOff
:FnOff
:AxesOn
:0→Xmin
:99→Xmax
:10→Xscl
:Menu(“*SCALE OPTIONS*”,“AUTO SCALE”,1,“MANUAL SCALE”,2,“QUIT”,3)
:Lbl 3
:Return
:Lbl 1
:-5→Ymin
:10→Ymax
:2→Yscl
:Goto 0
:Lbl 2
:ClrHome
:Prompt Ymin,Ymax,Yscl
:Lbl 0
:{1,0}→L1
:Send(L1)
:ClrHome
:{4,1,1,1,9.8,-9.8}→L1
:Send(L1)
:{1,1,14,0,0,1}→L1
:Send(L1)
:ClrHome
:Disp “REMOVE FORCE”
:Disp “FROM PROBE AND”
:Disp “HIT ENTER TO”
:Disp “ZERO.”
:Pause
:{3,.1,5,0}→L1
:Send(L1)
:5→dim L6
:Get(L6)
:(sum L6-max(L6)-min(L6))/3→Q
```

```
:ClrHome
:Disp "HIT ENTER TO"
:Disp "START FORCE"
:Disp "GRAPH."
:Pause
:{3,.1,-1,0}→L1
:Send(L1)
:99→dim L4
:ClrDraw
:Text(4,1,"FORCE(N)")
:Text(51,81,"T(S)")
:For(I,1,99,1)
:Get(L4(I))
:L4(I)-Q→L4(I)
:Pt-On(I,L4(I))
:End
:seq(N,N,0,9.8,.1)→L2
:9.8→Xmax
:1→Xscl
:Plot1(Scatter,L2,L4,•)
:DispGraph
:Text(4,1,"FORCE(N)")
:Text(51,81,"T(S)")
:Stop
```