EXPERIMENT 8
GRAPHICAL ANALYSIS OF MOTION

Problem

How can the motion of a body be analyzed?

Generally, the motion of a body keeps changing in both speed and direction from moment to moment. In this experiment you are going to analyze the motion of a body in a straight line by measuring its speed from moment to moment. You will obtain a picture of the changes that took place in the body's motion from a speed-time graph.

Apparatus

Cart; recording timer; timing tape; ruler; 200-g mass; stopwatch or watch with a second hand; plane mirror; dry cell; connecting wire

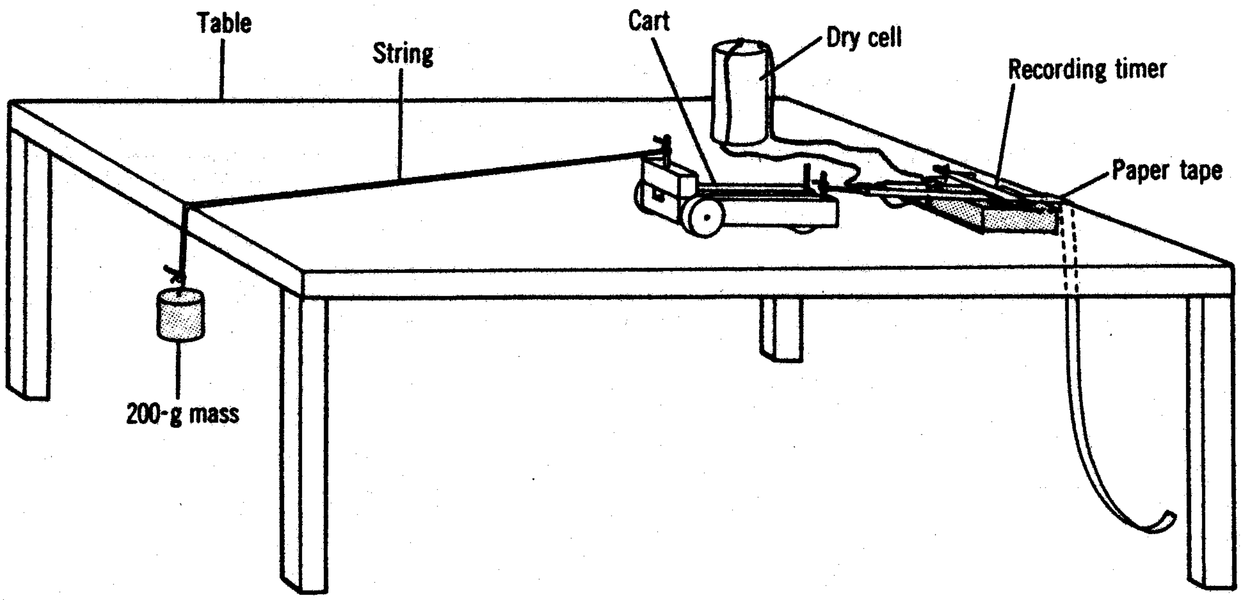

Fig. 8-1. Apparatus setup.

Needed Information and Skills

A distance-time record can be made of the motion of a body by attaching a paper tape to the body and letting it pull the tape through the recording timer, as in Fig. 8-1. The distance between any two consecutive dots is the distance traveled by the body during one vibration of the timer. That distance, divided by the period of the timer, is the *average* speed of the body over the time interval between the two dots. Often the speed of a body changes little over several time intervals. You can, therefore, take the *average* speed of the body over several time intervals around a given point as a good approximation of the *instantaneous* speed of the body at that point.

If the speed of the body is determined at a series of points on its path, these data can be used to make a *speed-time* graph of the body's motion. The slope of the graph at any point represents the *acceleration* of the body at that point and is numerically equal to it. It can be found by drawing the tangent to the curve at that point. Any two points on the tangent having coordinates (x_1, y_1) and (x_2, y_2) are then selected.

The slope is found from the ratio $\frac{y_2 - y_1}{x_2 - x_1}$. See Fig. 8-2.

The slope can also be found by measuring the angle A between the tangent line and the x axis (or a line parallel to the x axis) with a protractor and using a table of tangents to find the tangent of this angle. If the slope is zero, the acceleration is zero and the body is moving at constant speed. If the slope is positive, the body is speeding up. If the slope is negative, the body is slowing down.

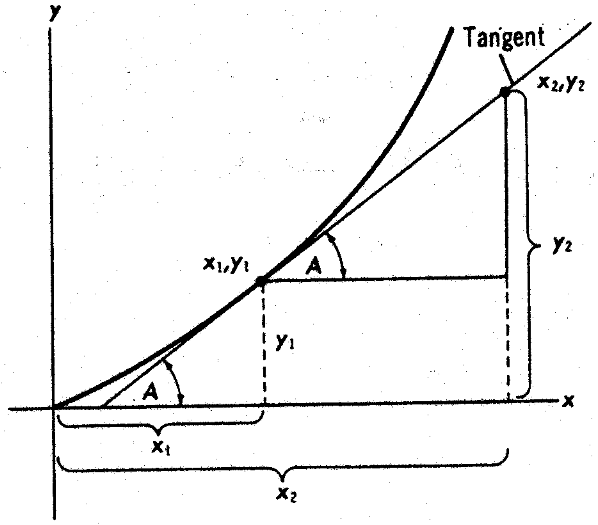

Fig. 8-2. Slope = tan A = $\frac{y_2 - y_1}{x_2 - x_1}$

An effective way of drawing a tangent to a curve at a point is to put a vertical plane mirror across the curve at the point. The mirror is then adjusted until there is smooth continuity between the curve and its image. A line is then drawn along the base of the mirror. The tangent to the curve is the perpendicular to this line at the point of tangency.

Gathering the Data

Before the timer can be used to measure time in seconds, its period of vibration must be measured. To do this, pull a length of paper tape through the timer for a measured 3 s as in Experiment 3. Count the number of dots on the tape. Divide 3 s by the number of dots to obtain the time required for 1 vibration of the timer. Do this two or three times, take an average of your values, and record this as the measured period of the timer.

Attach a string to a cart. Pass the string over the edge of the table and attach a 200-g mass to the other end of the string as shown in Fig. 8-1. Adjust the length of

Table 8-1

Dot No.	Travel Time t (s)	Distance d (m)	Speed $\bar{v}$ (m/s)	Dot No.	Travel Time t (s)	Distance d (m)	Speed $\bar{v}$ (m/s)
0				11			
1				12			
2				13			
3				14			
4				15			
5				16			
6				17			
7				18			
8				19			
9				20			
10				21			

the string so that the cart can move about 120 cm on the table. Attach a length of timing tape to the cart. Pass the other end of the tape through the recording timer and pull it back until the 200-g mass is about 30 cm above the floor. Set the timer operating and release the tape letting the 200-g mass pull the cart across the table. After the 200-g mass has struck the floor, let the cart continue to roll. Stop it when it reaches the edge of the table.

Remove the tape record of the motion. Number the first dot 0 and every tenth dot thereafter 1, 2, 3, etc. (see Fig. 8-3). Next to the number of each of these dots in Table 8-1, enter the travel time t corresponding to that dot. This is the time that has elapsed while the cart traveled the distance between dot 0 and that dot. The time t for each of the numbered dots is found by multiplying the number of the dot by 10 times the period of the timer.

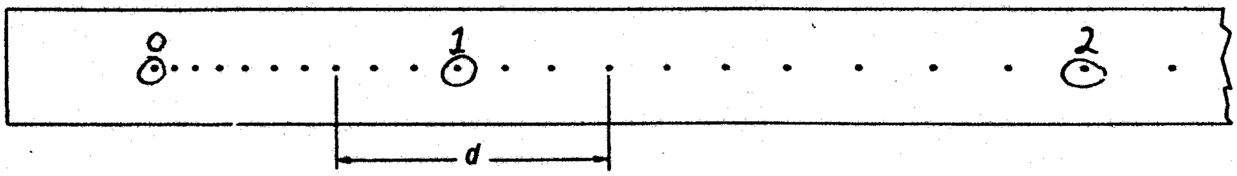

Fig. 8-3. Measuring d on the tape.

Next obtain the average speeds corresponding to each of the numbered dots. The speed of the cart at dot 0 is zero. To find the average speed of the cart at each of the other selected dots proceed as follows. Around each dot, mark off a distance d consisting of six consecutive intervals, three of which are on one side of the dot and three on the other. See Fig. 8-3. Measure d in meters for each dot and enter its value in Table 8-1. Each measured distance d was traveled by the cart in a time equal to 6 periods of the timer. Hence, the average speed $\bar{v}$, of the cart over each d, is found by dividing d by 6 times the period of the timer. Determine the average speeds corresponding to each of the selected dots and enter them in the table.

Solving the Problem

Plot the speeds $\bar{v}$ you have listed as ordinates against the corresponding times of travel t as abscissas. On your graph indicate the sections (if any) which show uniform motion, acceleration, and deceleration. Describe the motion of the cart in terms of the changing slope of your graph.

Select three points on the speed-time graph: one at which the acceleration is zero, one at which it is positive, and one at which it is negative. For each point determine the speed and acceleration and enter the values in Table 8-2.

Table 8-2

	Speed $\bar{v}$ (m/s)	Acceleration $\bar{a}$ (m/s²)
Point 1		
Point 2		
Point 3		

Questions and Supplementary Activities

1. How many significant figures are there in your values of the speeds?

2. What determines how large an interval you can use to get a good approximation of the speed at its mid-point?

3. What effect does the fact that the moving body is pulling the tape behind it have on its speed? Does this effect introduce an important error in the accuracy of the measurement you are making?

4. Fasten a pulley to the edge of the table opposite the recording timer. Tie a string to the cart and loop it over the pulley. Attach masses to the free end of the string until the cart barely moves across the table. Prepare a time tape for this motion of the cart. Make a speed-time graph and use it to analyze the motion of the cart.