EXPERIMENT 4
NEWTON'S SECOND LAW

I. THEORY

The purpose of this experiment is to test Newton's Second Law of Motion, which states that the net force acting on a body is equal to the product of the mass and the acceleration of the body.

$$\sum \vec{F} = m\vec{a}$$

When two or more bodies are combined into a system, Newton's Second Law applies to each mass individually, and also to the system as a whole; that is, the net force acting on the system is equal to the product of the total mass of the system and the acceleration of the center of mass.

In this experiment, a mass hangs from the end of a spark-sensitive paper tape which runs over a pulley. The other end of the tape is attached to a car running on a track. Before the tape is attached to the car, the track is tilted slightly so that the car will roll with a constant velocity toward the pulley, when give a small initial velocity in that direction. If this is done, the net force acting on the car will be zero before the paper tape is attached and equal to the tension in the paper tape once the tape is attached.

In our experiment, we will be neglecting any friction in the axle of the pulley as well as the mass of the pulley. This allows us to claim that the tension at both ends of the paper tape is equal. (The tension at both ends of the paper is very nearly equal for our pulley. The difference introduces only a very small error.)

We will test Newton's Second Law by experimentally determining the acceleration of the car. We will do this for seven different combinations of load mass and hanging mass. The acceleration will be determined using a spark timing system and kinematics equations. We will apply Newton's Second Law to the car with load and the hanging mass to obtain an expected relation between the acceleration due to gravity and the magnitude of the acceleration of the car and the acceleration due to gravity. Based on this relation and the acceleration of the car, we will calculate a value for the acceleration due to gravity for each run. If these values are in reasonable agreement with the known acceleration due to gravity, we may conclude that Newton's Second Law is verified.

As in the Acceleration Due To Gravity experiment, we will measure a series of successive distances traveled by the car during equal time intervals. We will use these distances to calculate the instantaneous velocity at the midpoint in time of each interval. To do this we will use the fact that when the acceleration of an object is constant during a time interval, the instantaneous velocity at the midpoint in time of the interval is equal to the average velocity during the interval. By knowing the instantaneous velocity at regular intervals, we will calculate the magnitude of the acceleration of the car using the Method of Differences.

II. LABORATORY PROCEDURE

1. Place the track on the laboratory table so that the pulley extends over the edge of the table. The pulley is the metal cylinder.

2. Level the track crosswise.

3. Place the car on the far end of the track, away from the pulley. Adjust the slope of the track so that the car rolls at a constant speed toward the pulley, once started. A slow speed is recommended. Again level the track crosswise.

4. Run the end of the paper tape over the pulley, with the outer spark sensitive side up. Extend the end down to the floor, and attach to the weight hanger clip. Hook the weight hanger into the clip. Bring the car to the lower end of the track, so it touches the car capture. Tear off a section of paper tape and attach the upper end to the car, with the weight hanger just touching the floor.

5. Place the movable spark terminal near one edge of the paper tape making the spark gap 1 or 2 mm. The spark gap is the distance between the sharp point on the movable spark terminal and the pulley. With the weight hanger just touching the floor, use a pencil to draw a line across the tape at the location of the spark terminal. This line will mark the transition from accelerated to nonaccelerated motion.

6. Connect the ground terminal of the spark timer (the black alligator clip) to the fixed terminal of the track. Connect the high voltage terminal of the spark timer (the red alligator clip) to the movable spark terminal of the track. Set the spark timer to 10 Hz (10 sparks per second).

7. Place a load of 1000 g on the car. Use only the 50.0 g weight hanger and the weight hanger clip as the driving mass. Move the car near the upper end of the track so that the weight hanger is just below the pulley. Hold the car there. Plug the spark timer into an AC outlet and turn it on. Allow it to warm up for about 30 seconds. After making sure that you are not touching a high voltage wire or terminal, press and hold down the high voltage button (the red button on the line switch). Release the car. Be prepared to catch the car in case it should jump the track. Release the high voltage button after the weight hanger strikes the floor.

8. For the second run, transfer 100 g from the car to the weight hanger. Move the spark terminal to a new position leaving room for the first four traces on the same piece of spark paper.

9. For the third run, transfer another 100 g from the car to the weight hanger.

10. For the fourth run, transfer another 100 g from the car to the weight hanger.

11. For the fifth run, remove all masses from the weight hanger. You should use a second piece of spark paper for the last three runs.

12. For the sixth run, remove 200 g from the car leaving the weight hanger empty.

13. For the seventh run, remove all masses from the car leaving the weight hanger empty. You should have a table on your data sheet indicating the load on the cart and the mass *added to* on the weight hanger and the run number, #1-#7. The mass *added to* the weight hanger should be zero for runs 1, 5, 6, and 7.

14. Measure the mass of the car and its attached clip on the balance. A "500 g" weight extender must be hung from the beam of the balance in order to increase its capacity by 500 g.

15. Measure the mass of the weight hanger clip. The weight hanger itself has a mass of 50.0 g.

16. For each trace, proceed as follows: Circle the last dot on the accelerated side of the line previously drawn, and label it 6. Label the next dot 5. Continue in this way until you reach dot 0.

17. Use the vernier caliper to measure each of the successive distances: 0-1, 1-2, …, 5-6, for each trace.

18. Before returning your equipment, put the weight sets in order: 500, 2-200, 100, 50, 2-20, and 10 g. Leave the movable spark terminal on the track.

III. CALCULATIONS AND ANALYSIS

1. Make a table with columns for time (1/20 s, 3/20 s, 5/20 s...) and velocity for each run. Each value of time listed is the underline midpoint of a time interval which is 1/10 second long.

2. Use the Method of Differences to calculate the average change in velocity per interval of time for each run. Show the calculation for run one. The Method of Differences is defined in the Introduction of the lab manual.

3. Use the result of step 2 to find the average acceleration for each run. Make a table showing values of hanging mass, the mass of the car and its load, total mass, acceleration, and calculated acceleration due to gravity (calculated in step 4) for each run. Do not forget to include the mass of the weight hanger clip and the weight hanger, when calculating the hanging mass.

4. Draw a free-body diagram for the hanging mass. Draw a free-body diagram for the car and load (include friction and the angle of the track). Why can the net force on the car and load be considered to be the tension in the paper tape? Using Newton's Second Law,

show how the acceleration due to gravity can be determined from the hanging mass, the mass of the car and load, and the acceleration of the car. You ***must*** apply Newton's Second Law separately to each object since the car and the hanging mass have different accelerations (different directions). Calculate an experimental value for the acceleration due to gravity from your data for each run. Record this value in your table from step 3.

5. Average your experimental values for the acceleration due to gravity and find the percent error, using 9.80 m/s² as the standard value.

6. Using the <u>standard</u> value for the acceleration due to gravity, calculate the weight of the hanging mass for each run. Make a table listing the run number, measured acceleration, the weight of the hanging mass, the total mass (car with load and hanging mass), and the reciprocal of the total mass for each run.

7. For runs 1-4, the total mass was not changed. For these runs, the acceleration should be directly proportional to the weight of the hanging mass. The graph of a direct proportion is <u>linear and passes through the origin</u>. To test the proportionality, plot a graph of acceleration versus weight of the hanging mass using these runs. Include the true origin of the graph, in order to test for a direct proportion. Draw the straight line which best fits the plotted points. Does the acceleration appear to be directly proportional to the resultant force? Calculate the slope of the line you have drawn. What physical quantity in this lab does the slope represent? Compare your slope to this physical quantity by calculating a percent difference.

8. For runs 1, 5, 6, and 7, the weight of the hanging mass was the same. For these runs, the measured acceleration should be inversely proportional to the total mass. To test this proportionality, plot a graph of acceleration versus the reciprocal of the total mass. Include the origin in your graph. Draw the straight line which best fits the plotted points. Does the acceleration appear to be inversely proportional to the total mass? Calculate the slope of the line you have drawn. What physical quantity in this lab does the slope represent? Compare your slope to this physical quantity.