

## Experiment 3: Newton's 2nd Law

In 1608, Galileo Galilei wanted to investigate the motion of falling objects. However, the objects fell too fast making it extremely difficult to measure their velocities and accelerations. His solution was to roll the objects down an inclined plane, thereby controlling the effective velocities, accelerations, times and forces. By the use of a frictionless air-track, we can make an even simpler system than Galileo's and use it to test Newton's second law of motion,  $F=ma$ . Our setup, similar to Galileo's, will have an object sliding down a frictionless inclined plane, as shown in Figure 1:

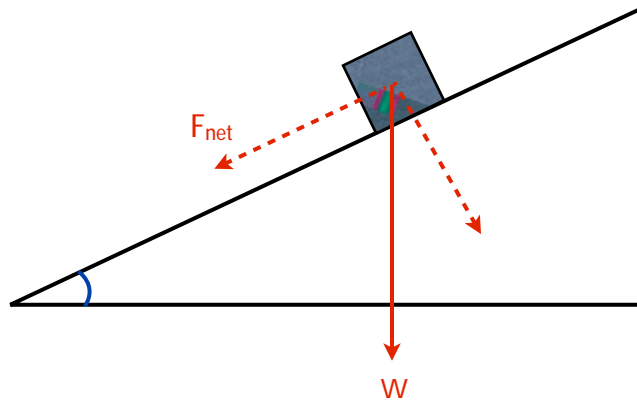


Figure 1: An object with weight  $W$  slides down a frictionless incline plane at an angle with respect to the horizontal direction.

The object we will use is a "glider" whose weight,  $W$ , can be varied by slotting on more mass. There are two forces acting on the glider: the weight pointing vertically downward and a normal force  $N$  pointing perpendicular to the inclined plane. The weight of the glider can be resolved into horizontal and vertical components with respect to the surface of the incline, as shown by the red dashed lines of Figure 1. Since only motion along the incline is permitted, the component of the weight along the incline,  $F_{net}$ , is the effective force applied to the glider. According Newton's second law

$$\mathbf{a} = \frac{\mathbf{F}_{net}}{m} \quad (1)$$

where  $m$  is the mass of the glider. This is the relation you will be testing with your experiments. By looking at the free body diagram of the sliding mass (see Figure 2), we can write the  $x$  and  $y$  components of the acceleration as

$$a_x = \frac{F_x}{m} = \frac{mgsin}{m} \quad (2)$$

$$a_y = \frac{F_y}{m} = \frac{N - mgcos}{m} \quad (3)$$

Figure 2: Freebody diagram for the sliding glider.

Thus the acceleration of the glider along the incline can be calculated by knowing the angle  $\theta$ . The acceleration can also be determined by measuring the instantaneous velocity experimentally and making use of the kinematic relation between acceleration and instantaneous velocity:

$$a = \frac{v^2 - v_0^2}{2x} \quad (4)$$

where  $x$  is the distance travelled,  $v_0$  is the initial velocity and  $v$  is the final velocity. The "instantaneous" velocity of a glider is measured (via Capstone) by timing how long it takes the glider, with a flag of known length, to pass through a photogate:  $v=L/t$ , where " $L$ " is the length of the glider's flag and " $t$ " is the time to pass through the photogate. The computer system and Capstone program will directly calculate the velocity of the glider as it passes through the photogate, provided that you insert the correct flag length,  $L$ , when you setup the timer.

### Experimental Objectives

In this laboratory you have an air track, a glider, a photogate, wooden or cardboard blocks to change the angle of incline, rulers, and different weights that can be placed onto the glider. The photogate is connected to a computer data acquisition system and velocity data can be collected using the computer software (see manual or ask the lab instructor about using this software with your experiment).

Devise an experimental procedure to test Newton's second law (Eq. 1) assertion that the acceleration is proportional to the effective force applied to the glider. Take a *thorough* set of measurements which will permit you to calculate the acceleration as a function of the effective force applied. Adjust the significant figures of the velocity readout to obtain the most accurate reliable measurements. Make sure that you have consistent data and report error bars in your data analysis. Include appropriate graphs which summarize your results.

Devise an experimental procedure to prove to yourselves that it is impossible to use a simple inclined plane to test the assertion that the acceleration is inversely proportional to the mass. Why is this so?

In order to minimize random errors, it is very important that each of your measurements be performed several times. Show error bars on your graphs. Make sure that you discuss all possible sources of systematic error in your experiments. In particular, think about and discuss whether the photogate system is measuring the true instantaneous velocity. Make sure to record all of the different masses, lengths, and angles you used and the velocities you obtained from the photogate.

## Questions

Answer these questions in your lab report. Show all work.

1. Calculate the accelerations using Equations 2 and 4 for the two experiments. Compare your results.
2. Derive an expression for the normal force. Do a sample calculation of the normal force for one of your data sets. What happens to the normal force if the incline angle is completely vertical ( $\theta = 90^\circ$ )? How about when horizontal?
3. Select one of the velocities you obtained from the second experiment. If the glider goes *up* the incline with that initial velocity, how far up the plane will it go? How much time would it take for the glider to return to the starting point?