Forces and Newton’s 2nd Law

Overview

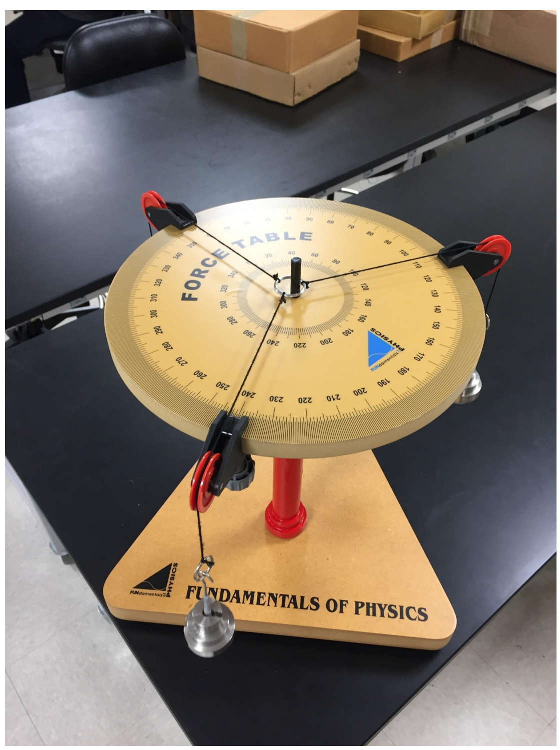
In the previous lab you used graphs to study how an object, a golf ball, moved when it was dropped from a short distance above the floor. The study of how things move is called kinematics. In this lab you are going to study *why* things move, or more specifically, why does the motion of an object change. The explanation is Newton’s 2nd Law. Newton’s second law says when there is a net force on an object, then the object's motion (velocity) will change; i.e., the object will accelerate.

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

Newton’s 2nd Law seems simple, but there is a lot going on in the equation above. First on the left hand side we have to consider all of the forces acting on the object and add them together. Since forces are vectors we have to use *vector* addition to determine the net force.

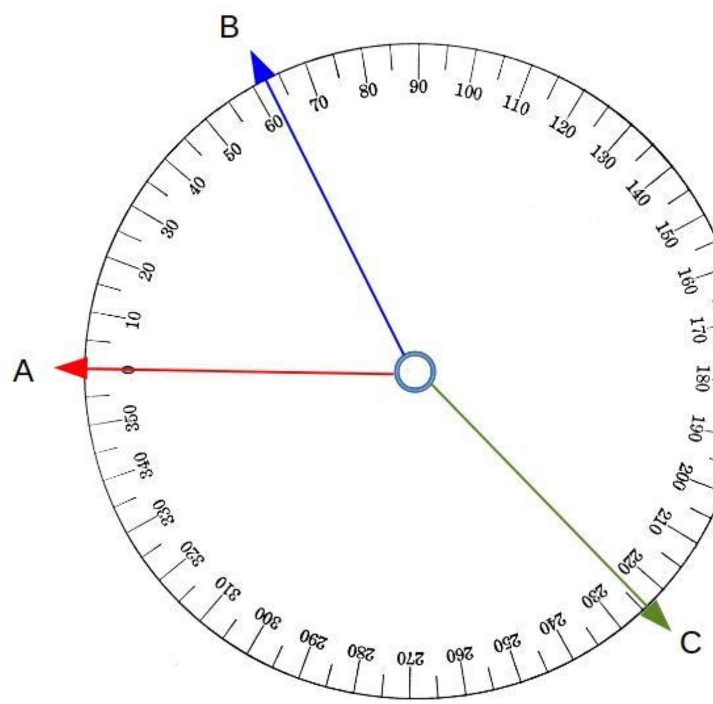
Part 1 - Vector Addition

For the first part of the lab you will consider a static case, when the net force is zero. You will start by using a force table.



The force table shown above has three hanging weights positioned at three different places around the force table. The weights are attached to a small ring near the center of the table by three strings. Each string exerts a force on the ring. The *magnitude* of the force can be changed by changing the amount of weight hanging, and the *direction* of the force can be changed by adjusting the position of the pulley.

Since the ring is at the center of the table and the ring is not moving and not accelerating, that must mean the combination of the three forces, the net force is zero. But each of the individual forces on the ring are not zero. This is only possible if the *vector* addition of the three forces is zero.



Let's start by labeling the three forces $\vec{A}$, $\vec{B}$, and $\vec{C}$. The vector sum of these three forces is:

$$\vec{A} + \vec{B} + \vec{C} = 0$$

If you are given the magnitude and direction of $\vec{A}$ and $\vec{B}$, you can solve for the magnitude and direction of $\vec{C}$.

$$\vec{A} + \vec{B} = -\vec{C}$$

- Obtain from your TA values of magnitude and direction for forces $\vec{A}$ and $\vec{B}$. Record the values in the table below.

Magnitude A	Direction A	Magnitude B	Direction B
100g	30 deg	150g	105 deg

You will *first* make a prediction of direction and magnitude of $\vec{C}$ using the $\vec{A}$ and $\vec{B}$.

1. Define a coordinate system for the force table. What are the x- and y-components of $\vec{A}$ and $\vec{B}$?

A = <100cos(30), 100sin(30)> B = <150cos(105), 150sin(105)>

2. Using the components of $\vec{A}$ and $\vec{B}$, what are the components of $\vec{C}$?

<-100cos(30)-150cos(105), -100sin(30)-150sin(105)>

3. What is the magnitude of $\vec{C}$? 200g
4. What is the direction of $\vec{C}$? 256°

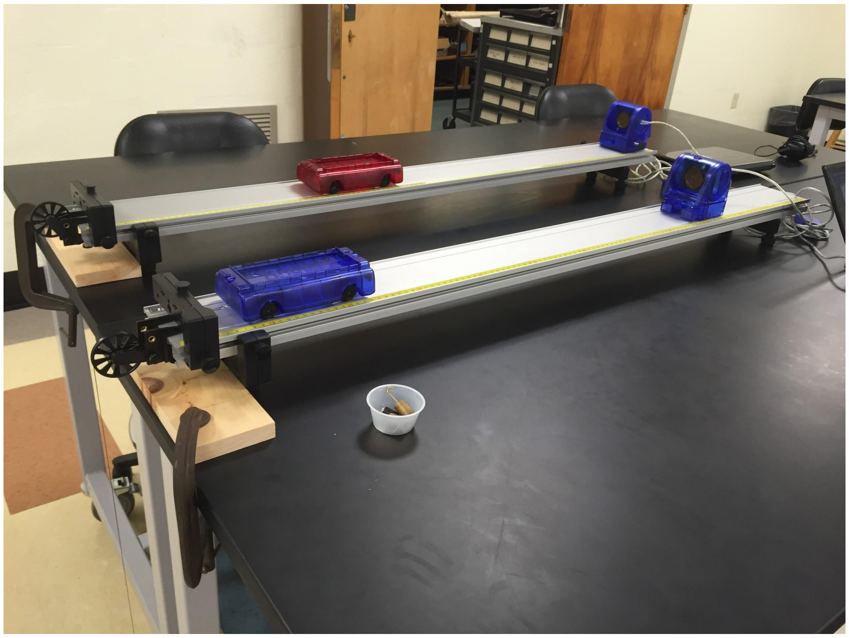
Now set up the three forces on the force table. First setup $\vec{A}$ and $\vec{B}$ using the values given by your TA. Then setup $\vec{C}$ using the values of magnitude and direction from your prediction.

5. Is the ring connected to the three forces centered on the force table? Adjust the magnitude and direction of $\vec{C}$ until the ring is centered on the table. Record the adjusted values of $\vec{C}$.

Magnitude C	Direction C
200	256

Part 2 - Newton's 2nd Law

Now let's look at what happens when the net force on an object is not zero. On your lab table is a PASCO track and PAScar. The PAScar is attached to a string with a hanging weight.



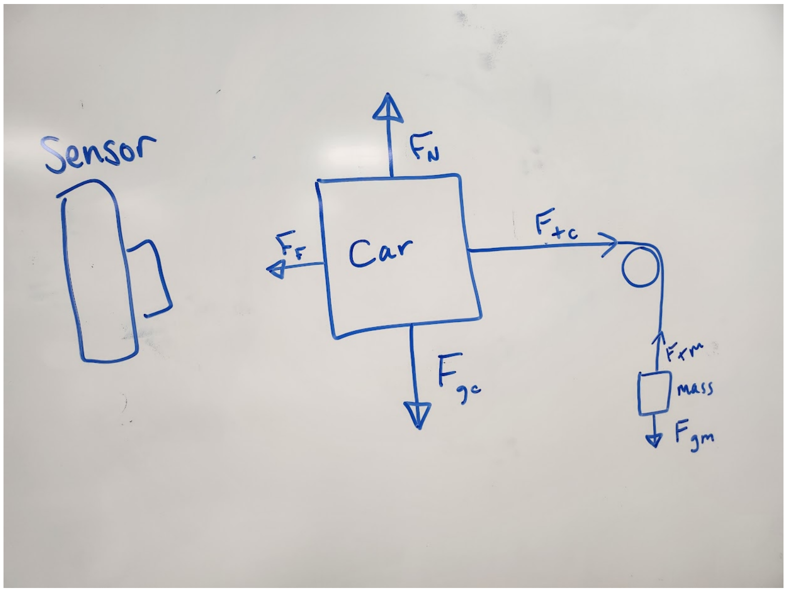
A motion sensor is positioned on the end of the track to measure the motion of the PAScar. If there is a net force on the PAScar, it will accelerate according to Newton's 2nd Law. The acceleration of the PAScar will depend on the mass of the PAScar.

Now if the PAScar is allowed to move, it will roll down the track *away* from the motion sensor. At the opposite end of the track is a magnetic bumper. The PAScar bumps the bumper and can move in the direction *towards* the motion sensor.

Let's consider the motion of PAScar away from the sensor and towards the sensor separately. Even in this case of 1-D motion, direction still matters! We need to define a coordinate system in 1-D, and we need to choose which direction is positive and which direction is negative. The motion sensor measures the position of the PAScar as increasing when it moves away from the sensor and measures position decreasing when the PAScar moves towards the sensor. Away from the sensor is the positive direction and towards the sensor is negative.

6. Draw a [free body diagram]() of the Pascar AND the hanging mass when the Pascar is moving away (positive) from the sensor. You can draw it on a whiteboard in the lab and take a picture and insert it into your report. Make sure you lab all the forces, including

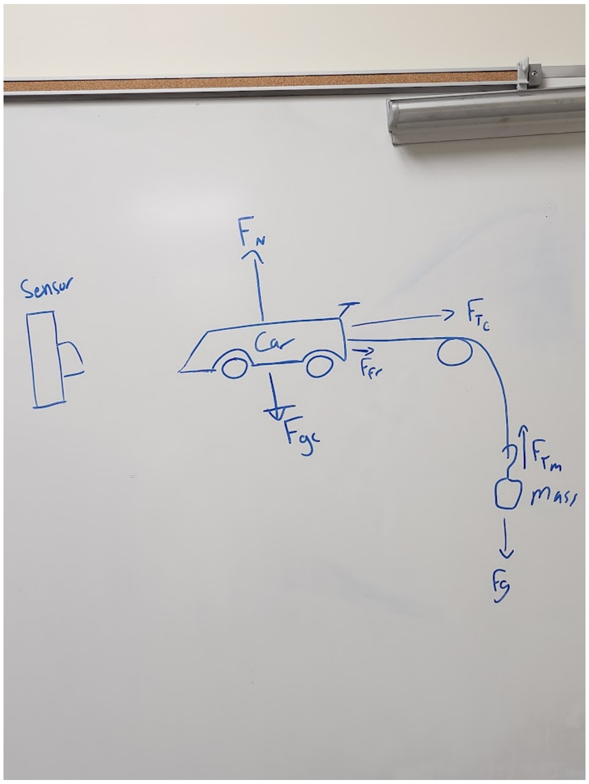
friction, in the free body diagram.



7. What is the direction of the velocity (positive or negative) when PAScar moves away from the sensor? How does the velocity determine the direction of any friction force?

When the PAScar moves away from the sensor the velocity is positive because the distance is increasing, velocity determines the direction of friction because it is opposite the direction of the velocity.

8. Using Newton's 2nd Law, write a mathematical expression for the net forces and the acceleration of the PAScar when PAScar moves away from the sensor.
   $F_F+F_{tC}=ma$ $F_{CN}+F_{Cg}=0$
9. Draw a [free body diagram]() of the Pascar AND the hanging mass when the Pascar is moving towards (negative direction) the sensor. You can draw it on a whiteboard in the lab and take a picture and insert it into your report. Make sure you lab all the forces, including friction, in the free body diagram.



10. Is the direction of the friction force the same when the PAScar moves towards the sensor as the direction of friction force when the PAScar moves away from the sensor? Why or why not.
    The friction force is not the same because it is opposite of the direction the car is moving in
11. Using Newton's 2nd Law, write a mathematical expression for the net forces and the acceleration of the PAScar when the PAScar moves towards the sensor.
    $-F_F+F_{tC}=ma$ $F_{CN}+F_{Cg}=0$

Now let's do the experiment. Start with a 5 gram hanging mass on the end of the string. Hold the PAScar approximately 50 cm in front of the motion sensor. Click Record in Capstone and release the PAScar. Allow the PAScar to move 3 or 4 times towards and away from the sensor.

Capstone will plot the velocity vs. time of the PAScar. Note that at some intervals of time the PAScar has positive velocity (away) and at other intervals of time it has negative velocity (towards).

Use the analysis tools at the top of the graphing window to measure the acceleration of the PAScar when it moves away from the sensor and when it moves towards the sensor.

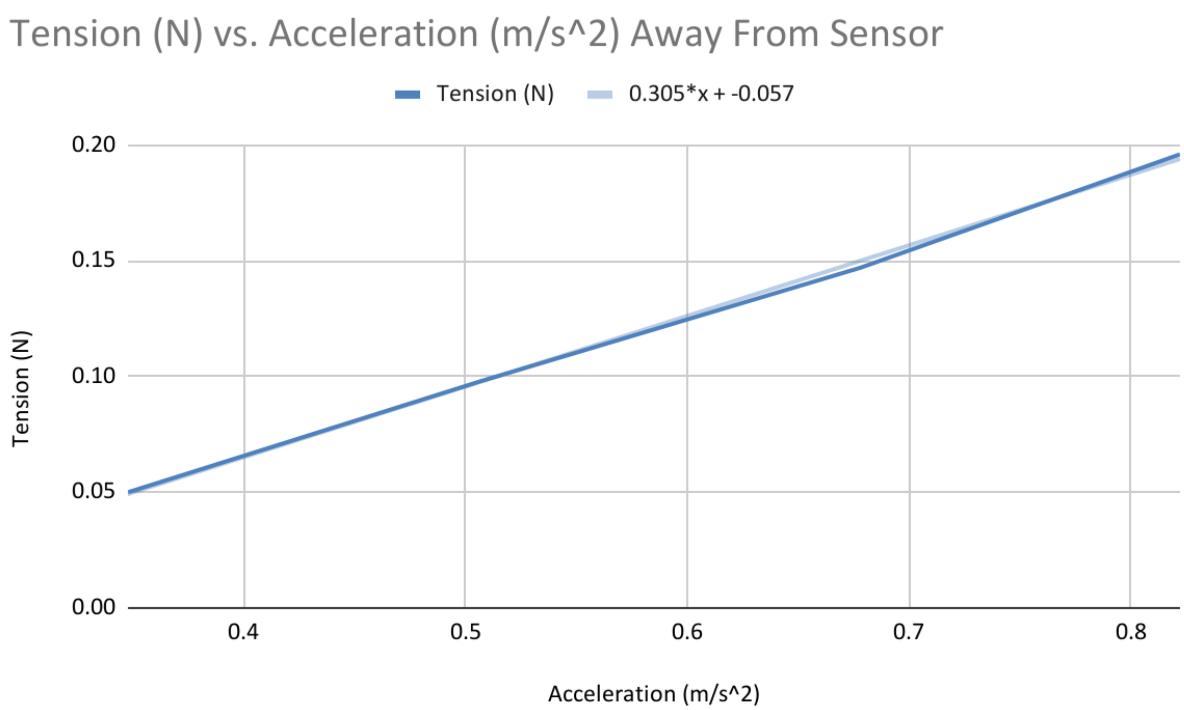
12. Are the accelerations of the PAScar towards the sensor and away from the sensor the same? Why or why not?

They are not the same because when the car is moving towards the sensor, the force of friction and force of tension are working together, while in the case where the car is moving away from the sensor, the forces are counteracting each other.

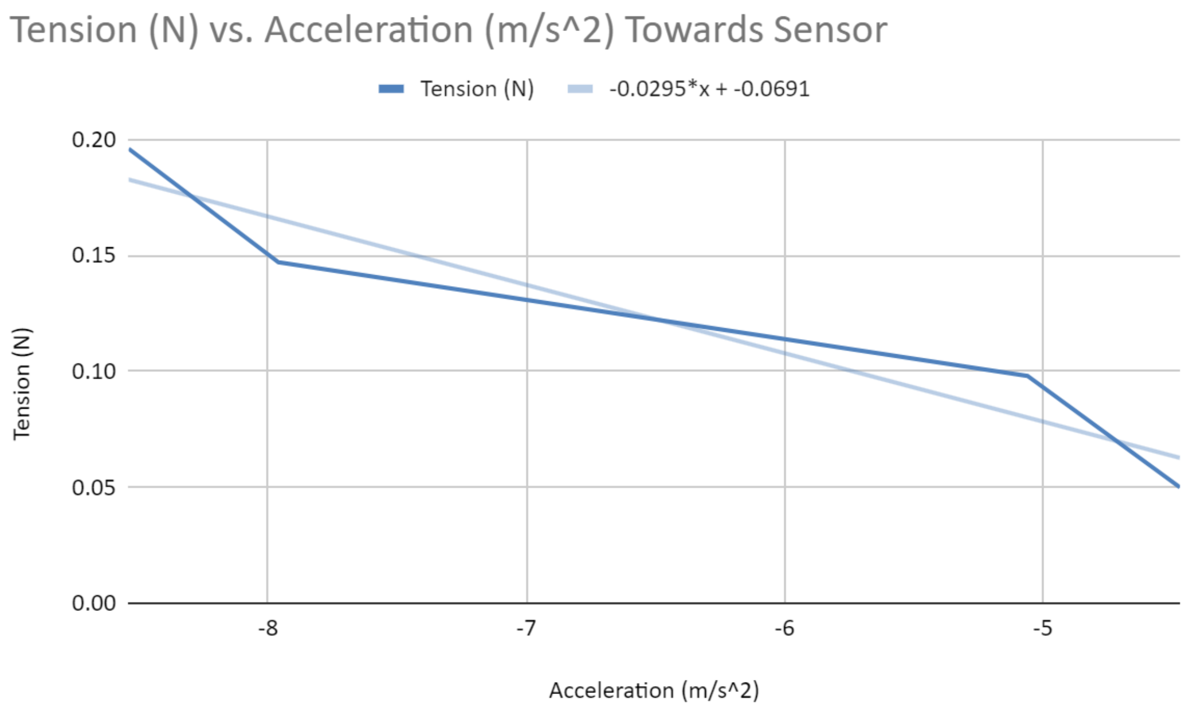
13. Record the values for acceleration away and towards the sensor for different values of hanging mass 5, 10, 15 and 20 grams in the Google Sheet.

Now let's analyze the tension vs. acceleration for both moving towards and away from the sensor.

14. Make a plot of Tension vs. acceleration of PAScar moving away from the sensor. According to your expression of Newton's 2nd Law in question 8, what do the slope and intercept of your plot represent?



15. Make a plot of Tension vs. acceleration of PAScar moving towards sensor. According to your expression of Newton's 2nd Law in question 11, what do the slope and intercept of LINEST() your plot represent?
The slope and intercept of LINEST represent the linear relationship between acceleration and tension, the intercept represents when acceleration is 0, the tension force on the car is negative.



16. Now use LINEST() to fit the best line to Tension vs. acceleration for both motion away and towards the sensor? Is the sign of the intercept different for motion towards and away from the sensor? Explain why.

The signs for both intercepts are the same because the tension and acceleration forces act on each other the same when acceleration is 0.

17. What is the mass of the PAScar according to your analysis?

.3 kg