Experiment 2

Newton's Second Law and forces

1. Purpose

To learn how to determine the velocity and the acceleration of a moving object individually by multi-functional counter and photodetector, a video anlysis software called "Tracker", and Arduino with Coolterm, and to furthur apply Newton's Second Law to determine the unknowns.

2. Introduction

In high school, we have already learned to accept Newton's Laws without question, and any experimental data that contradict the second law would immediately alert us to an error in procedure or analysis, or worse, reinforce the widely held opinion that simple laws are inadequate to explain the behavior of "real" systems. This experiment first focuses on how to verify the second law with different softwares, and then apply the understanding of Newton's laws to determine the unknowns in the laboratory apparatus.

3. Theory

If an object is subject to external forces, the velocity will change, and experiments show that for a given object, the acceleration is linearly proportional to the net force, which in mathematical description is

$$\overrightarrow{F} \propto a \tag{3.1}$$

Moreover, experiments also show that under a given force, the acceleration is inversely linearly proportional to the intrinsic quantity of the object, mass, which in mathematical description is

$$\overrightarrow{a} \propto \frac{\overrightarrow{F}}{m} \tag{3.2}$$

Therefore, we conclude that

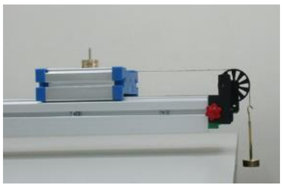
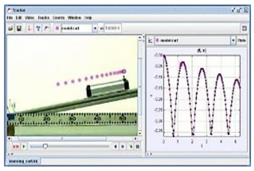
$$\overrightarrow{F} = k \cdot m \cdot \overrightarrow{a} \tag{3.3}$$

where m represents the mass of the object, and k is a proportionality constant. It is our choice to take k to be 1. All it changes is merely how we define mass. Thus, Newton's 2^{nd} law is simply that

$$\sum_i \overrightarrow{F_i} = m\overrightarrow{a} \tag{3.4}$$

Note that the inertia of a body is its tendency to resist any change in its state of motion; therefore, mass of a body is a measure of its inertia, that is, its resistance to change in velocity.

4. Apparatus and software

				
Cart and track with pulley and hanger	Multi-functional counter	Photodetector	Tracker	Arduino Mega Case +CoolTerm

5. Procedures

(1) Pre-lab assignments (hand in before the experiment with no more than 2 pages A4)

1. Read the instructions for use of the multi-functional counter carefully so as to understand how to use it to measure the quantities
2. Download Tracker[1], drive for Arduino Mega case[2] and CoolTerm[3], and see tracker tutorial[4] on youtube in advance
3. Make a flowchart of this experiment and answer the questions

(i) During the experiment, you will have the apparatus consisting of a cart of unknown mass M, situated on a track, connected by a thread to a hanging mass m, as shown in Fig. 1. When the cart is released, the cart accelerates, the pulley turns, and the multi-funcational counter with two photodetectors will measure the speeds of the cart at two different positions, which gives you the acceleration of the cart. The track is tilted by a small unknown angle θ, where friction is small but significant, illustrated in Fig. 2.

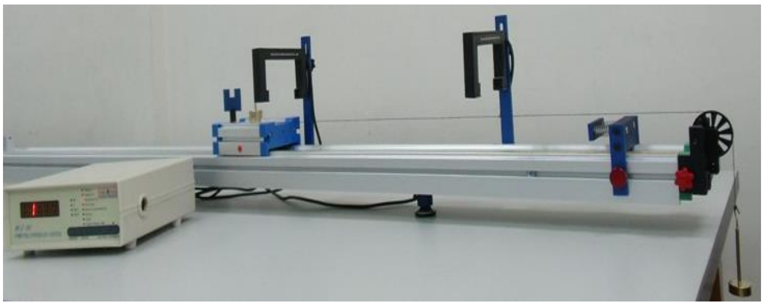


Figure 1. The experimental setup.

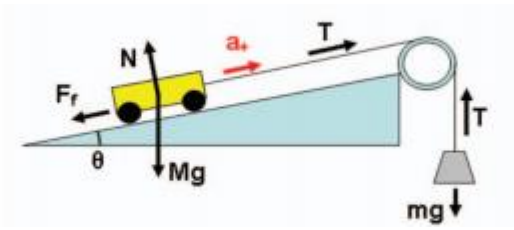


Figure2. Schematic of the experiment

[1] To install Tracker, download and run the appropriate installer via the link: http://physlets.org/tracker/
[2] To install the drive for Arduino Mega Case: https://www.arduino.cc/en/software
[3] To install CoolTerm: http://freeware.the-meiers.org
[4] To get started with Tracker: https://www.youtube.com/watch?v=La3H7JywgX0

(a) We know that for m significantly larger than $M \sin\theta$, the cart moves up the sloping track with an acceleration a_+, and instead descends the slope with the acceleartion a_- for significantly smaller values of m. If the effective friction force is regarded as a constanat force $\left|\overrightarrow{F_f}\right|$ opposing the motion, derive the equations for $a_+(m)$ and $a_-(m)$.

(b) With the results of (a), you can imagine that the accerleration of the cart with changing hanging mass will be quite nicely described by two straight lines, with x-intercepts at m_+ and m_- where $a_\pm = 0$. Find $\left|\overrightarrow{F_f}\right|$ by $m_\pm$.

(c) Find the mass of the cart M by approximating the slope of a_- with $M \gg m$, and find the angle θ by the results you obtained.

(d) Find another simple way to obtain the friction $\left|\overrightarrow{F_f}\right|$, and describe your idea.

(ii) Find the acceleration of the cart in the given video by fitting data obtained via Tracker. You have to attach the $x-t$ plot with more than 10 data points obtained from the video first and then explain how you calculate the acceleration. Note that the length scale should be calibrated by the ruler on the track in the video.

(2) In-lab activities

1. Set up the equipment, as shown in Fig. 1.

(i) Mount the end stop to the track just in front of the pulley.

(ii) Determine the length of thread to have the mass hanger be near the floor when the cart reaches the end stop of the track. One end of the thread should be attached to the hook on the wireless force acceleration sensor, the other end of the thread should be tied to the mass hanger.

(iii) Adjust the angle of the pulley so that the thread is parallel to the track. (Why?)

(iv) Be sure the track is level, and find a way to prove you are right. (Hint: $\left|F_f\right|$)

(v) Measure $\left|F_f\right|$ by Multi-functional counter with photodetector

(a) Fix two photodetectors at the proper positions

- **(b)** Press **FUNCTION** to change the mode to "Acceleration," where you can get the velocities at two positions, and the average acceleration
- **(c)** Press **CHANGEOVER** for more than 1 second to set $3.0\ \text{cm}$ for U-shaped baffle plate (Why $3.0\ \text{cm}$?)
- **(d)** Hold the cart still at the position right before the first photodetector, and then release it to obtain data
- **(e)** Press **FUNCTION** to remove data, independently redo the experiment for at least 5 times to obtain the best estimate for the friction $\left|F_f\right|_{\text{best}}$.

2. Verify the second law: The cart on a untilted horizontal track with the hanging mass $m \cong 50\ \text{g}$ and $m \cong 60\ \text{g}$ individually.

(i) By Multi-functional counter with photodetector

- **(a)** Fix two photodetectors at the proper positions
- **(b)** Press **FUNCTION** to change the mode to "Acceleration," where you can get the velocities at two positions, and the average acceleration
- **(c)** Press **CHANGEOVER** for more than 1 second to set $3.0\ \text{cm}$ for U-shaped baffle plate (Why $3.0\ \text{cm}$?)
- **(d)** Hold the cart still at the position right before the first photodetector, and release it to obtain data
- **(e)** Press **FUNCTION** to remove data, independently redo the experiment for at least 5 times to obtain the best estimate for the acceleration $a_{\text{M,best}}$.

(ii) By Arduino Mega Case and CoolTerm

- **(a)** Connect the Arduino Mega case to laptop via Signal 1, and run CoolTerm.
- **(b)** Use the transmission lines to connect the sensor on the cart with the Arduino Mega case by their colors: black→**OUT**, red →**VCC**, and blue →**GND.**
- **(c)** Push **RUN** to start tracking, release the cart and stop it while arriving at the end for at least 2 seconds, and data will be collected in CoolTerm
- **(d)** Copy the data from CoolTerm to the data sheet in Excel to store it
- **(e)** Push **RESET** to remove data, and find the best estimate for the acceleration $a_{\text{A,best}}$.

(iii) By Tracker

- (a) Record a video of the motion of the cart by your phone and transfer it to the laptop. (*** You are suggested to do this part with part (i) at the same time.)
- (b) Use Tracker to obtain at least 10 data points from the video to draw a $x-t$ graph of the motion (***Don't forget the calibation of the length scale.)

(c) Find the best estimate for the acceleration $a_{\mathrm{T,best}}$ and compare the results you obtained in part (i), part(ii) and part(iii) with the theorical result.

3. Measure the unknowns inherent in the apparatus
   (a) Place a speically-made block under the track to tilt it by a small angle θ.
   (b) Reacll the results in the part 3 of the pre-lab assignments. Apply them to design an experiment to obtain the mass of the cart M, the tilted angle θ, and the effective friction force $\left|F_f\right|$.

(3) Post-lab report

1. Recopy and organize your data from the in-lab tables in a neat and more readable form.
2. Analyze the data you obtained in the lab and answer the given questions
3. Compare the results obtained by different methods, and discuss the uncertainties that occur in the experiments, and how they influence the experiments. (Quantitatively, if possible.)

6. Questions

(1) Try to obtain the coefficient of friction between the cart and the track and state it in the standard form. Is the result the static or the kinetic friction coefficient between them? Why?

(2) Is the friction between the cart and the track dependent on the speed of the cart? Explain.

(3) Is the friction between the cart and the track dependent on the tilted angle? If so, can it be linearly dependent? If not, why? Explain by providing a physical image instead of proving it mathematically.

(4) In the pre-lab assignments, you are asked to find the mass of the cart M by assuming $M \gg m$. Can you avoid using the approximation that $M \gg m$? Find the relation, replace the data you fetched in this experiment and compare the result with the one you obtained by the approximation.

7. Reference

[1]Carl E Mungan 2012 *Phys. Educ.* **47** 288