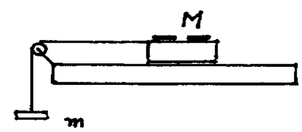
Experiment: <u>Newton's Second Law of Motion</u>

<u>OBJECTIVE</u>: To find how the magnitude of **acceleration depends on** the **applied force** and the **mass**.

<u>INTRODUCTION:</u>



In this experiment, a glider with mass **M** is moving at constant acceleration along a horizontal air track under the effect of a pulling force. The pulling force is applied by attaching a piece of thread to the glider, passing it over a pulley and hanging a mass "**m**" to its other end. By changing mass "**m**" value one can change the magnitude of pulling force.

You will use a device called "***photogate with pulley***" to measure the magnitude of acceleration. On one side of it is mounted an infrared light emitting diode and on the other end a photocell. When the pulley rotates, its holes allow light to pass and the photocell turns on and off. The software uses the produced signal to calculate the magnitude of thread **velocity** (*equal to that of moving masses (glider M and mass m*) and draws the graph ***υ=υ(t)***.

MODELLING AND THEORETICAL BACKGROUND OF THE LAB

At t = 0s the system of two blocks A,B is left free to start moving from rest. They follow an accelerated motion with the same magnitude of acceleration i.e. $\boldsymbol{a_A} = \boldsymbol{a_B} = \boldsymbol{a}$.
Figure 1 shows the forces exerted on each block : $\vec{F}_{G-B}$, $\vec{F}_{Air\_press}$, $\vec{T}_B$, $\vec{F}_{G-A}$, $\vec{T}_A$. In this experimental set up, the pressure of air track avoids the friction force and simultaneously produces a vertical component that cancels the action of gravitational force on block B. The gravitational force on block A plays the role of a pulling force.
Figure 2 shows a "Isolation diagrams " for each of two blocks moving with same acceleration.
The calculations in figure3 , based on application of the second law for motion of each mass, bring to expressions

$$\boldsymbol{F_{pull} = F_{G-A} = (m_A + m_B)a = Ma}$$

$$\boldsymbol{a = \frac{1}{M} * F_{pull}} \qquad (1)$$

This relation shows that the magnitude of acceleration is proportional to the magnitude of pulling force (F_{pull}=F_{G-A}) and inverse proportional to the *moving mass* (M= m_a+m_b).

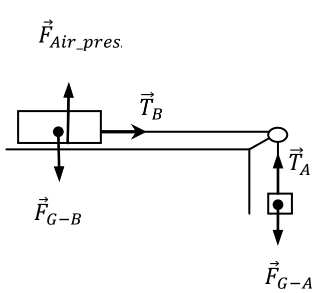


Fig.1 Identifying external forces applied on system (two blocks)

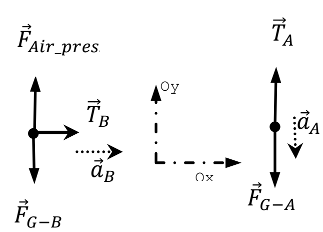


Fig.2 FBD for each block and axes

Object B: Ox: T_B=m_B*a_B ;
Object A: Oy: T_A - $F_{G\text{-}A}$ =- m_A*a_A *or* T_A = $F_{G\text{-}A}$ - m_A*a_A

As the magnitudes $\boldsymbol{T_A = T_B \equiv T}$ *and* $\boldsymbol{a_A = a_B \equiv a}$ *one get*

T_B= T =m_B*a_B = $\boldsymbol{m_B}$***a*** = T_A = $F_{G\text{-}A}$ - m_A*a_A = $\boldsymbol{F_{G\text{-}A}}$ **-** $\boldsymbol{m_A}$***a***
i.e. m_B*a + m_A*a = $F_{G\text{-}A}$
or F_{pull} = $F_{G\text{-}A}$ = (m_A +m_B)*a = M*a *from which one get expression (1)*

Fig.3 Derivation of expression(1)

Measurement procedure:

1) Turn the air pressure "on" and place the medium size (*black*) glider on the air track. If does not stand at rest you have to level the track. Next, push it a little and make sure that it slides without friction (*at constant velocity*) on the track. Then, attach a piece of thread to the glider, run it over the pulley and fix a slot mass **m** to the other end. Plug the lead from the smart pulley into digital input #1 on the Science Workshop interface.

2) To study the ***dependence of acceleration on the applied force***, one will change the magnitude of pulling force by hanging different slot masses **m** and using the expression $F_{pull} = 9.8 * \mathbf{m}$ to calculate its magnitude.

3) To prepare the recording of data, at first make sure to turn on the computer and the interface.
   - Open Capstone software and click on Hardware Setup in upper left-hand corner. If the interface is on, but still the software cannot see it, you will need to reboot the computer.
   - Click on Add Sensor/Instrument downside the interface picture. Select Science Digital sensor and ***Photogate with pulley*** *from* the list of sensors.
   - We use two types of smart pulleys (with 3 holes and with 10 holes). Capstone needs to know which one is being used. To insert this information, click on Proprieties (at hardware picture). A new window will open. At its bottom there is two specifications (Spoke arch length(m) and Spoke angle (^{o}). **Enter 0.05m and 120^o for pulley with three spokes and 0.015m and 36^o for the pulley with 10 spokes.**

   - Click again on Hardware pic to suppress it. To set up a graph, click on the graph icon in the upper right-hand corner in Display panel. Click on Select Measurement tab to specify the quantities to plot. If you want to add a new graph click on Add new plot area icon in the graph toolbar.
   - Click on the Record button on the bottom left to record a set of data.

4) Measure the total mass of the glider $\mathbf{m_{gl}}$**[kg]** by using a *mass balance*.
   - Hang a slot mass **m =10g** at end of string. Next, collect the data as follows:
   - Push the "Air" button on the air track and hold it. Once the glider starts to move, click Record button.
   - Just before the glider hits the end of the track, click Record button anew to stop recording.
   - Examine the velocity versus time graph and make sure that there is a straight part on it. If not, check the air track and glider and try again.

Finding the acceleration from the graph $\upsilon = \upsilon(t)$ on Capstone

Find the slope of the graph $\boldsymbol{\upsilon = \upsilon(t)}$ (i.e. the *acceleration*) as follows:
- With the mouse pointer, draw a box around the points on the graph which are aligned around a long portion of the straight line; omit those that might exhibit friction (*generally at the beginning and end*).
- Click **Fit** at the top of the graph window and select **Linear Fit**.
- In the box that appears, select the **slope** (equal to **a**) and its **standard deviation** (its *uncertainty* **Δa**).

5) **Experiment_1**; "***The dependence of acceleration on the magnitude of applied force***"

Start by setting up table#1 on your data sheet. Measure the mass $\mathbf{m_{Gl}}$ of the glider. Attach equal number of slot masses to each side of the glider (start with m_{att} = 40+40= 80*g*), fix a thread to the glider and hang $\mathbf{m_A}$**=** ***10g*** slot mass to the other end of string. So, you will start measurement with a pulling force F_{pull} = 0.098N. Next, push on the air button and leave the set to slide free. Collect a set of data for velocity and time on Capstone. Fit the straight part of graph v = v(t) on screen to a linear function and get the acceleration **a**, and its uncertainty **Δa**. Next, remove 10g from m_{att} and hang them at string end. This operation makes $\mathbf{m_A}$**=** *20g*, m_{att} = 35+35= 70*g* and allows to keep m_{att} **+** $\mathbf{m_A}$**= 90g**. After that, collect another set of data. You will Repeat these steps for different values of $\mathbf{m_A}$ (10, 20, 40, 60 and 80g). Insert data for F_{pull}, **a** and **Δa** in table #1.

Keep constant the total sliding mass **$M = m_{Gl} + (m_{att} + m_A) = m_{Gl} + 0.09$kg** during all these measurements.

Tab# 1 **$M = (m_{Gl} + m_{att} + m_A)$ kg**

N#	m_A[kg]	$F_{pull} = 9.8*m_A$[N]	a[m/s^2]	Δa[m/s^2]
1	10g	0.098		
2	20g	0.196		
3	40g	0.392		
4	60g	0.588		
5	80g	0.784		

Plot the graph#1 of ***a*** vs. ***F_{pull}*** (for *constant total sliding mass M*) with data in table #1. Fit it to a straight line passing by origin; record the slope and its uncertainty. Show in graph the "error bars" of **a** values.
If the absolute uncertainty is too small to produce visible error bars, note that under the graph.

6) **Experiment_2;** " ***<u>The dependence of acceleration of a moving set of objects on their mass</u>*** "

The hanging mass must be kept the same **m_A =20g (**or 10g**)** (i.e. ***constant pulling force***) but the ***<u>total moving mass</u>*** $M = m_{Gl} + m_{att} + m_A$ must be ***changed*** by a significant amount. One can do this by using three gliders with different size and adding slot masses on them. Start by measuring their mass on the balance and record them as M_L, M_m, M_s . Initially, place on the air track the larger size glider $M_1=M_L$. Check that the glider slides along the track without friction (*you have to verify this before any recording*). Attach a thread to the glider and **m_A= 20g(**or 10g**)** to the other end. Collect a set of data as before and record the acceleration **a**, and its uncertainty **Δa** in table# 2.
Next, place the medium size M_m glider on air track, attach the same mass slots (ex: 30g / 30g , i.e. ***m_{att}=60g***) on its both sides and record the acceleration **a** and **Δa** with **m_A =20g (**or 10g**) for mass** $M_2 = M_m + m_{att}$.
Then remove mass slots (i.e. ***$m_{att} = 0$***) and repeat measurements for $M_2 = M_m$.
Follow similarly with small glider with masses M_4 and M_5 . This way you will record acceleration for five different sliding masses. Select ***m_{att}*** of slots so that these masses be distributed *as equally as possible* between M_L and M_s . Fill the second column of table#2 with $M = m_{Gl} + m_{att}$ and third column with corresponding total moving mass ***$M+m_A$***. Include in table the measured values for acceleration. Calculate **($M+m_A$)*a** and related uncertainty **($M+m_A$)*Δa**. Plott graph#2 of ***a*** vs. ***($M+ m_A$)*** with the data in table 2; trace the best fitting line and identify its type(linear, power, exponential,..).

Table# 2 Constant pulling force = m_A*9.81= 0.02*9.8=0.196[N]

No	M [kg]	$M+m_A$[kg]	a[m/s^2]	Δa[m/s^2]	($M+m_A$)*a	Δ[($M+m_A$)*a]
1	$M_1 = M_L$	M_1 + 20g				
2	$M_2= M_m + m_{att}$	M_2 + 20g				
3	$M_3= M_m$	M_3 + 20g				
4	$M_4= Ms + m_{att}$	M_4 + 20g				
5	$M_5= Ms$	M_5 + 20g				

<u>ANALYSIS AND CONCLUSIONS:</u>

1) What represents the slope of the **a** vs. **F_{pull}** in graph#1? Does its value agree with the expected value?
2) What is the type of relationship between **a** and the moving mass from graph #2? Does it fit to relation (1)?
3) Do the results of your experiments fit to the second law of Newton predictions? How do you know? Explain.