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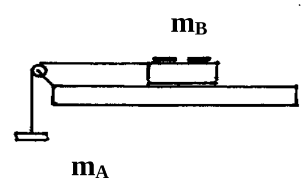
Experiment: <u>Newton's Second Law of Motion</u>

<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 $\mathbf{m_B}$ **slides** at constant acceleration over a horizontal air track under the effect of a pulling force. One applies a pulling action by attaching a piece of thread to the glider, passing it over a pulley and hanging a mass "$\mathbf{m_A}$" to its other end. The pulling force is equal to $F_{G-A} = m_A$*g. One changes the magnitude of pulling force by changing mass "$\mathbf{m_A}$"

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 **speed e***qual to that of moving masses (glider m_B and mass mA*) and draws the graph ***v=v(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 at 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 two "Isolation diagrams ", one for each of two blocks.
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 *total mass in motion* (i.e. $M = m_a + m_b$).

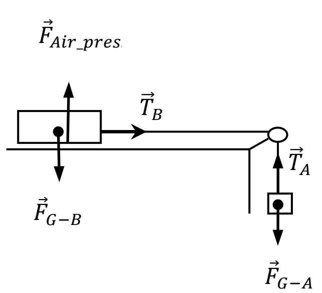


Fig.1 Identifying external forces applied on system (two blocks)

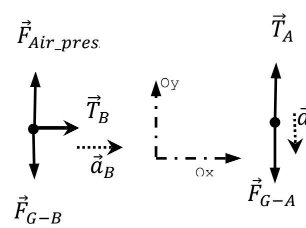


Fig.2 FBD for each block and axes

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

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

$T_B= T =m_B*a_B = \boldsymbol{m_B*a} = T_A = F_{G-A} - m_A*a_A = \boldsymbol{F_{G-A} - m_A*a}$
i.e. $\boldsymbol{m_B*a + m_A*a = F_{G-A}}$
or $F_{pull} = F_{G-A} = (m_A + m_B)*a = M*a$ *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 $F_{pull} = 9.8 * m$ 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 $v = v(t)$ on Capstone

Find the slope of the graph $v = v(t)$ (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} = 70*g* and allows to keep $m_{att} + m_A$**= 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} + 0.09kg** during all these measurements.

Tab# 1 Constant sliding mass: **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_B + m_A** = (**m_{Gl}** + ***m_{slot}*** **) + 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 " **m_{Gl}** "on the balance and record them as M_S, M_m, M_L. Initially, place on the air track the smaller size glider M_1=M_S. Check that the glider slides along the track without friction (*you have to verify this before each 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 glider M_m = M_3 on air track, attach and **m_A= 20g(**or 10g**)** to the other end record acceleration. Do the same with larger size glider, too.
Then, you will place a few slots on M_s so that the M_s+m_{slots}=M_2 be somewhere around (Ms+Mm)/2 and record the acceleration. Next, you will place a few slots on M_m so that the M_m+m_{slots} =M_4 be somewhere around (Mm+M_L/2 and record the acceleration.
This way you will record acceleration for five different sliding masses. Select ***m_{slot}*** so that these masses be distributed *as equally as possible* between M_L and M_s .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 ***F_{pull}*** = 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_s	M_1				
2	M_2= Ms + m_{slots}	M_2 + m_{slots}				
3	M_3= M_m	M_3				
4	M_4= Mm + m_{slots}	M_4 + m_{slots}				
5	M_5= M_L	M_5				

<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.