CHAPTER 1

Newton’s Second Law

1. Equipment List:

- Air Track with Air Pump
- Air Car
- Four 50.0 gm Masses
- 2 Photogates & Timer
- Pulley
- Mass Hanger
- Weights
- Electronic Balance

2. Physics:

The quantitative study of motion is a key element of physics. One of the most important types of motion is that of an object traveling with a constant acceleration in a straight line. In this lab falling weights will furnish the constant acceleration, and you will utilize the photogates and timer for acquiring your data and the EXCEL program for processing your data.

This experiment is to verify the fundamental law of dynamics, Newton’s 2nd Law, \( \vec{F} = M\vec{a} \). This says that if the mass \( M \) of an object is constant, then the acceleration of the object \( \vec{a} \) is directly proportional to the force acting on it \( \vec{F} \). It also says that if the force acting on an object is constant, then its acceleration is inversely proportional to \( M \). A test of the law is suggested by these proportionalities, namely:

1) for a given mass, measure \( \vec{a} \) and \( \vec{F} \) and find if they are directly proportional; and
2) for a given force, measure \( \vec{a} \) and \( M \) and find if they are inversely proportional.

3. Introduction:

The apparatus, as shown in figure 1, consists of an air car riding on a level air track, with a falling mass \( m \) attached to the car by means of a pulley \( P \). Photogates \( PG \) are used to time the motion of the air car and thus the hanging mass \( m \). The car itself can have its mass changed by attaching weights (in pairs) to the pins on both sides of the car body.

EXCEL can analyze the motion of the car if you provide data consisting of a series of measurements of the position of the car as a function of time. Since the car’s motion obeys:

\[
x = x_0 + v_0 t + \frac{1}{2} at^2
\]
1. NEWTON'S SECOND LAW

![Newton's 2nd Law Apparatus](image)

**Figure 1. Newton’s 2nd Law Apparatus**

You have already had some experience (using the EXCEL program) in fitting such a function to data measured in the lab. However, you may have found the task of getting a “best fit” through the points to be a difficult one to do by hand. Fortunately, a statistical method, the **method of least squares**, also exists for finding the best-fit parameters of the motion \((x_0, v_0\) and \(\frac{1}{2}a\) in equation 1 above) as well as their standard deviations (quantitative expressions of their uncertainties based upon the data distribution given). When running the EXCEL program for your data, simply choose the appropriate functional model, and once the data and function are displayed on the screen hit the “Fit” key combination. The least-squares fit will be performed.

The Least-Squares algorithm in EXCEL also calculates uncertainties in the best-fit parameters by determining how sensitive the reduced chi-squared (or \(S\) factor) is to changes in the value of each parameter.

4. Procedure

4.1. **First Run.** Measure the mass of your air car using the pan balance. Now add two 5 gm masses and four 5 gm masses to the side pins of the car. Set up the apparatus as shown in the figure, passing the thread over the pulley, through the hole in the air track bumper, and along a horizontal line to the air car. Place no extra mass no the hanger; it has a mass of \(\approx 5\) gm. Set your starting gate at one side of the air track, and the finish gate at a known distance from the start gate toward the pulley.

From a point just before (as close as possible) where photocell 1 is tripped on, release the cart from rest. The car passing through photogate 2 will trip the gate and the time will be displayed on the timer. Make at least three trails and use the average time in your analysis. Keep all of your data in a table in your lab manual. Move
the photocell 2 to a new “known position” and repeat this process. You will want
measurements for at least 5 positions.

Enter your data which describes the motion of the car along the air track as displacement vs. time in \([t, x]\) pairs into the EXCEL program. Excel will autoscale the data and select a quadratic-polynomial model. Perform a least-squares fit of the data to equation 1. Get a printed plot of your fit, along with a printout of the parameters of the motion and their uncertainties. (Include both of these in your Log Book.) Record the value you have thus determined for the car’s acceleration as well as the uncertainty in that acceleration in the space below:

<table>
<thead>
<tr>
<th>Car’s Total Mass ((M))</th>
<th>(= )</th>
<th>(\text{gm})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falling Mass ((m))</td>
<td>(=)</td>
<td>(\text{gm})</td>
</tr>
<tr>
<td>Car’s Acceleration ((a))</td>
<td>(=)</td>
<td>(\text{cm/}^2)</td>
</tr>
</tbody>
</table>

4.2. Constant Mass. Design an experiment to test the direct proportionality of acceleration to pulling force, when the mass \((M)\) is held constant. Describe your experiment in your log book, including theory, procedure, and data tables for all measurements taken. (Don’t forget to include uncertainties where appropriate.)

Use Excel to test the direct proportionality of acceleration with pulling force. Include any needed data tables in your log book, and attach all computer output to your book.

4.3. Constant Force. Design an experiment to test the inverse proportionality of acceleration to mass, when the pulling force \((mg)\) is held constant. Describe your experiment in your log book, including theory, procedure, and data tables for all measurements taken. (Don’t forget to include uncertainties where appropriate.)

Use EXCEL to test the inverse proportionality of acceleration with mass. Include any needed data tables in your log book, and attach all computer output to your book.

5. Questions

1) How well do the proportionality relationships you have tested seem to hold true? Discuss the significance of the values obtained for the fit parameters. (Be sure to state the uncertainties obtained for these parameters.)
2) If your fit parameters are related to known physical properties of the system, compare your EXCEL-determined values to the known values. Do they agree? If not, are there any additional sources of experimental error that have not been directly accounted for in your analysis?
6. Pre-Lab Questionare

1) Summarize the general procedures that will be used to measure acceleration in this lab exercise.

2) Suppose that one experiment has been run, and that the timer provides you with a series of measurements of the position of the car vs. time. Given these data, using EXCEL, plot a graph of $x$ vs. $t$ and determine the acceleration of the car. Bring a hard copy of your graph and a printout of the fit parameters to lab.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$t$</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>6</td>
<td>4</td>
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