Laboratory Investigation E1:

Newton's Second Law

Experimental Overview

Key Concept:
Newton's Second Law reveals a profound relationship between force, mass, and motion: The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. Mathematically, we express this as:

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

This investigation explores three fundamental relationships that together illuminate the elegant mathematical structure of motion:

1. The linear relationship between force and acceleration (constant mass)
2. The inverse relationship between mass and acceleration (constant force)
3. The linear relationship between acceleration and reciprocal mass (constant force)

Using specialized physics software, we'll measure accelerations directly as we systematically vary forces and masses, revealing the mathematical patterns that govern motion at the most fundamental level.

Investigation Strategy

Our approach mirrors the scientific method at its best: we'll isolate and study each variable's influence by holding others constant. This method of controlled variation lets us discover how each factor contributes to the overall behavior of the system.

Materials and Equipment

- Dynamics track with motion sensor
- Dynamics cart (mass 0.180 kg)
- Set of 5g masses for hanging
- Pulley system
- Computer with experiment software and Excel
- String (approximately 1m)

Safety Considerations

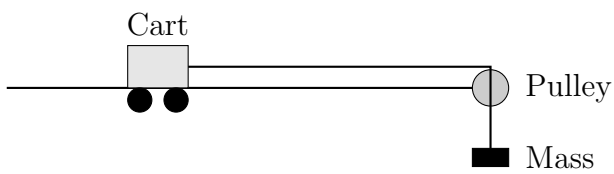
Safety Protocol

- Secure the track firmly to prevent tipping
- Verify pulley alignment before starting
- Handle masses carefully to prevent dropping
- Keep fingers clear of moving parts
- Ensure string is properly tied to prevent masses from falling

Part 1: Force and Acceleration

Investigation Focus:
We examine how acceleration changes when we vary the applied force while keeping mass constant. The software directly measures the cart's acceleration for each applied force.

Experimental Setup



Procedure

1. Level the track using the adjustable feet
2. Measure and record the cart's mass (M_c)
3. Attach the string to the cart and over the pulley
4. Add a 5g mass (0.005 kg) to the hanging end
5. Calculate the applied force: $F = mg = 0.005 \text{ kg} \times 9.81 \text{ m/s}^2 = 0.049 \text{ N}$
6. Start the data collection in the software
7. Record the measured acceleration
8. Add another 5g mass
9. Repeat steps 5-7 until you have data for all five masses (3-5 measurements each mass)

Data Collection

Record your measurements in this format:

Hanging Mass (kg)	Applied Force (N)	Measured Acceleration (m/s^2)
0.005	0.049	
0.010	0.098	
0.015	0.147	
0.020	0.196	
0.025	0.245	

¿ **Data Pattern Note**:
¿ Each 5g increase in hanging mass adds exactly 0.049 N of force, creating a systematic progression ideal for discovering mathematical relationships.

Part 2: Mass and Acceleration

¿ **Investigation Focus**:
¿ We now explore how acceleration changes with mass while keeping force constant. This reveals the inverse relationship at the heart of Newton's Second Law.

Procedure

1. Keep the hanging mass constant at 10g (0.098 N)
2. Start with the original cart mass
3. Record the acceleration
4. Add a 50g mass to the cart
5. Record the new acceleration
6. Repeat steps 4-5 for four more measurements

Data Collection

Record your results in this format:

Cart + Added Mass (kg)	Force (N)	Acceleration (m/s^2)
0.1826	0.098	
0.2326	0.098	
0.2826	0.098	
0.3326	0.098	
0.3826	0.098	

Part 3: Advanced Analysis

¿ **Mathematical Insight**:
¿ By plotting acceleration versus 1/m, we transform the inverse relationship into a linear one, revealing another face of Newton's Second Law.

Create a new column in your spreadsheet for 1/m and plot a vs. 1/m. The slope of this line should equal your applied force.

Data Analysis in Excel

Creating Effective Scientific Graphs

For each relationship, create a scatter plot:

1. Select appropriate columns for x and y axes
2. Insert → Scatter Plot
3. Add clear axis labels with units
4. Include a descriptive title
5. Add a trendline and display its equation

Expected Relationships:

- F vs. a: Linear with slope = 1/m
- m vs. a: Inverse (hyperbolic)
- 1/m vs. a: Linear with slope = F

Discussion Questions

1. How does doubling the force affect acceleration? Is this what you'd expect from $F = ma$?

2. Why does acceleration decrease as we add mass to the cart?
3. What physical meaning does the slope have in each graph?
4. How do your results support or challenge Newton's Second Law?
5. What sources of systematic error might affect your results?
6. How could this experiment be improved?

Conclusion Guidance

Your lab report conclusion should synthesize:

- The three mathematical relationships discovered
- How well your data supports Newton's Second Law
- Major sources of experimental uncertainty
- Connections between theory and experiment
- Suggestions for experimental improvements

¿ **Final Reflection**:
¿ Consider how Newton's insight about force, mass, and acceleration reveals fundamental patterns in nature. These relationships govern everything from the motion of atoms to the orbits of planets.