**Experiencing Newton’s Laws**

**General instructions for the report:**

1. Group report: turn in one report for your entire group. Due date: see web.

2. Format:

* The report must be word-processed or your longhand must be very legible.
* Your answers must be in *italic* or in **boldface** to distinguish them from instructions.
* The graphs may be neatly drawn by hand and have to be integrated into the text (not attached, not on different pages).

3: More specific instructions for the report are given inside this document.

**Introduction:**

The purpose of this lab is to have you do *everyday life* experiments and analyze them using your newly acquired knowledge of Newton’s laws. Some of these experiments you may have done in the past but never really thought about. Maybe you have some intuition for what the answers are. However, our intuition and preconceived notions are not always correct. I hope that you will be baffled and irritated by some of the experiments and that a careful analysis with the tools learned in class will come to your rescue. Throughout the lab, try to understand your misconceptions and how Newton’s Laws allow you to find the right answer.

**Notes:**

1. In all of your FBDs **use the subscript notation** introduced in class, e.g. $\vec{N}\_{AB}$ is the *normal force* exerted *on* object A *by* object B. Don’t forget subscripts for any force, including friction. For example, if you draw the static friction exerted on a block by the table, the answer $\vec{f}^{s}$ is incomplete. The correct answer would be $\vec{f}\_{BT}^{s}$.

2. If an object is sliding relative to the table, the resulting friction is **kinetic**, if it is not moving relative to another object, the resulting friction is **static** (or there is no friction). Use subscripts *s* for static and *k* for kinetic.

3. Make sure that all your observations, kinematics, FBDs and your equations are **consistent**. Examples:

1. If $\sum\_{}^{}F\_{x}=m\_{B}a=T\_{BA}-N\_{BW}$ (with a>0) your FBD should have a tension $\vec{T}\_{BA}$ acting in the positive x-direction (don’t forget the coordinate system ☺) and a normal force $\vec{N}\_{BW}$ acting in the negative x-direction. $\vec{T}\_{BA}$ should be longer than $\vec{N}\_{BW}$.
2. In this case the object with mass $m\_{B}$ should have been observed to accelerate in the positive x-direction (acceleration). It could have moved to the right, to the left, or been instantaneously stationary (velocity).

4. **Do not invent forces!** Carefully use the technique for identifying forces that you learned in class. If the system touches the table there could be contact forces (a normal force and friction). If all contacts between the system and the environment are investigated there are no more contact forces! Even if you ‘*need them to make it fit with your intuition’*. Maybe you need to revise your intuition.

5. Have fun! Realizing that what you thought to be right is actually incorrect is a good thing. Learning is all about eureka moments ☺.

General info and tips:

1. If a rope or string connecting two objects is massless we can use the massless string approximation:

1. The tension on both sides of the string has the same magnitude.
2. In this case we are allowed to bend the strict rule of distinguishing between the immediate and the ultimate cause of a force a bit: If objects A and B are connected by a massless string, then the tension exerted on object A by the string S should technically be called $\vec{T}\_{AS}$ and the tension exerted on object B by the string should be called $\vec{T}\_{BS}$. Since the forces on the massless string are the reaction forces of these two tensions, $\vec{T}\_{SA}$ and $\vec{T}\_{SB}$we are allowed to think of the tensions between A and B as $\vec{T}\_{AB}$ and $\vec{T}\_{BA}$ even though A and B are technically not in contact. Use this revised notation in your FBDs. Note that this is only true for a massless string.

**Part 1: The Physics of Tug O’ War**

A common misconception about tug of war is that the winning team is the one that pulls harder on the rope. In this exercise, you will use your knowledge of Newton’s laws to investigate the physics of tug of war. We will neglect the mass of the rope.

Get together with another group and play TWO safe rounds of tug of war.

* Round 1: both teams should wear shoes, and the contest should take place on the vinyl floor outside the lab.
* Round 2: the winning team from round 1 will take off shoes, and the contest should take place on the vinyl floor outside the lab.

**Tug Of War, Round 1, Observations and Analysis**

The coefficients of friction k and s, depend (among others) on what materials are in contact (e.g. shoes touching vinyl floor). In round 1 …

Team A was wearing \_\_\_\_\_\_\_\_\_\_\_ and standing/moving on \_\_\_\_\_\_\_\_\_\_\_\_

Team B was wearing \_\_\_\_\_\_\_\_\_\_\_ and standing/moving on \_\_\_\_\_\_\_\_\_\_\_\_

The winner was team \_\_\_\_\_\_.

|  |  |
| --- | --- |
| **Team A** (the team on the left) | **Team B** (the team on the right) |
| **Observed motion** team A | **Observed motion** team B |
|  | **Velocity**:Use an arrow to indicate the direction of motion for team A (zero for no motion). | **Velocity**:Use an arrow to indicate the direction of motion for team B (zero for no motion). |  |
|  | **Acceleration**:Use an arrow to indicate the direction of the acceleration of team A (zero for no acceleration). | **Acceleration**:Use an arrow to indicate the direction of the acceleration of team B (zero for no acceleration). |  |
|  | **Walking/Sliding/No Motion**:Was team A walking (W), sliding (S) or not moving (zero)? | **Walking/Sliding/No Motion**:Was team A walking (W), sliding (S) or not moving (zero)? |  |
| **FBD** Team A: | **FBD** Team B: |
| In the boxes below, draw FBDs for teams A and B. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Neglect the mass of the rope. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations** Team A | Newton’s 2nd Law **Equations** Team B |
| $$A:\sum\_{}^{}F\_{x}= = $$$$A:\sum\_{}^{}F\_{y}= = $$ | $$B:\sum\_{}^{}F\_{x}= = $$$$B:\sum\_{}^{}F\_{y}= = $$ |
| Rank all horizontal forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

Are your observations, FBDs and equations consistent?

**Tug Of War, Round 2, Observations and Analysis**

The coefficients of friction k and s, depend (among others) on what materials are in contact (e.g. shoes touching vinyl floor). In round 1 …

Team A was wearing \_\_\_\_\_\_\_\_\_\_\_ and standing/moving on \_\_\_\_\_\_\_\_\_\_\_\_

Team B was wearing \_\_\_\_\_\_\_\_\_\_\_ and standing/moving on \_\_\_\_\_\_\_\_\_\_\_\_

The winner was team \_\_\_\_\_\_.

|  |  |
| --- | --- |
| **Team A** (the team on the left) | **Team B** (the team on the right) |
| **Observed motion** team A | **Observed motion** team B |
|  | **Velocity**:Use an arrow to indicate the direction of motion for team A (zero for no motion). | **Velocity**:Use an arrow to indicate the direction of motion for team B (zero for no motion). |  |
|  | **Acceleration**:Use an arrow to indicate the direction of the acceleration of team A (zero for no acceleration). | **Acceleration**:Use an arrow to indicate the direction of the acceleration of team B (zero for no acceleration). |  |
|  | **Walking/Sliding/No Motion**:Was team A walking (W), sliding (S) or not moving (zero)? | **Walking/Sliding/No Motion**:Was team A walking (W), sliding (S) or not moving (zero)? |  |
| **FBD** Team A: | **FBD** Team B: |
| In the boxes below, draw FBDs for teams A and B. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Neglect the mass of the rope. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations** Team A | Newton’s 2nd Law **Equations** Team B |
| $$A:\sum\_{}^{}F\_{x}= = $$$$A:\sum\_{}^{}F\_{y}= = $$ | $$B:\sum\_{}^{}F\_{x}= = $$$$B:\sum\_{}^{}F\_{y}= = $$ |
| Rank all horizontal forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

Are your observations, FBDs and equations consistent?

**Tug Of War: more analysis and questions**

1. Consider system S consisting of both teams A and B (and the rope, of course).

Assume that team A is winning and walking backwards to the left with an increasing speed. Team B is sliding to the left, with the same velocity and acceleration as team A.

|  |
| --- |
| **System S (A and B combined)** |
| **Observed motion** |
| **←** | Velocity |
| **←** | Acceleration |
| walking and sliding | Part of S was sliding, part was walking so we need to draw **two** friction forces and **two** corresponding normal and gravitational forces. To distinguish the forces, we have to find different names for the normal-force-on-S-by-the-ground-G-that-acts-on-team-A and the normal-force-on-S-by-the-ground-G-that-acts-on-team-B, etc. Use $\vec{N}\_{SG}^{A}$ and $\vec{N}\_{SG}^{B}$. Do the same for the friction forces and weight. |
| **FBD of system S:** | **Equations for system S:** |
|  | $$S:\sum\_{}^{}F\_{x}= = $$$$S:\sum\_{}^{}F\_{y}= = $$ |
| Rank all horizontal forces in terms of their magnitude and explain how you know (N2 or N3) |

2. Explain why the statement *“the team that pulls harder wins”* is wrong.

3. The statement *“ the team that pushes harder on the ground wins”* is not necessarily true. Explain this using your observations and the equations $f\_{k}=μ\_{k}N$ and $f\_{s}^{max}=μ\_{s}N$. Give an example for when this statement is wrong.

4. What can you do to push harder on the ground?

5. Who really wins? The team that wins \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**Part 2: The Mystery of Salami & Spring Scales**

1. **Prediction:**

Below is a figure showing the three basic salami positions. If the Salami has a mass of 200 grams predict what the scale reading will be for each situation.

1. Hanging Salami - Scale Reading = \_\_\_\_\_\_\_
2. Salami & the Wall - Scale Reading = \_\_\_\_\_\_\_
3. Salami vs. Salami - Scale Reading = \_\_\_\_\_\_\_

Case i

C

B

B

B

A

A

200g

200g

Case iii

200g

Case ii

200g

A

1. **Experimental Results:**

Set up the three situations and **record** the scale reading.

1. Hanging Salami - Scale Reading = \_\_\_\_\_\_\_
2. Salami & the Wall - Scale Reading = \_\_\_\_\_\_\_
3. Salami vs. Salami - Scale Reading = \_\_\_\_\_\_\_
4. **Analysis**

Draw FBDs for the salami(s) and the scale in each situation. (Ignore the weight of the scale; assume the strings have no mass and cause no friction.). Fill out the tables below and convince yourself that the experimental results make sense.



**Case i:**

|  |  |
| --- | --- |
| **FBD** A (Scale) | **FBD** B (Salami): |
| In the boxes below, draw FBDs. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Neglect the mass of the strings. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations** for A | Newton’s 2nd Law **Equations** for B |
| $$A:\sum\_{}^{}F\_{y}= = $$ | $$B:\sum\_{}^{}F\_{y}= = $$ |
| Rank all forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

Notes:

**Case ii:**

|  |  |
| --- | --- |
| **FBD** A (Scale) | **FBD** B (Salami): |
| In the boxes below, draw FBDs. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Neglect the mass of the strings. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations** for A | Newton’s 2nd Law **Equations** for B |
| $$A:\sum\_{}^{}F\_{x}= = $$ | $$B:\sum\_{}^{}F\_{y}= = $$ |
| Rank all forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

Notes:

**Case iii:**

|  |  |  |
| --- | --- | --- |
| **FBD** A (left salami) | **FBD** C (scale) | **FBD** B (right salami) |
| In the boxes below, draw FBDs. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Neglect the mass of the strings. Mark action-reaction pairs of forces. |
|  |  |  |
| N2 Law **Equations** for A | N2 Law **Equations** for C | N2 Law **Equations** for B |
| $$A:\sum\_{}^{}F\_{y}= = $$ | $$C:\sum\_{}^{}F\_{x}= = $$ | $$B:\sum\_{}^{}F\_{y}= = $$ |
| Rank all forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

**D. Summary**

Write a paragraph explaining why the scale readings are what they are. Refer to your FBDs:

**Part 3: Book and Paper**

**Case 1: Slow Pull** Place a book on a piece of paper and pull the paper slowly such that the book stays on the paper. ***Neglect any friction between the paper and the table***.

|  |  |
| --- | --- |
| **Book B**  | **Paper P** |
| **Observed motion Book B** | **Observed motion Paper P** |
|  | **Velocity**:Use an arrow to indicate the direction of motion for the book (zero for no motion). | **Velocity**:Use an arrow to indicate the direction of motion for the paper (zero for no motion). |  |
|  | **Acceleration**:Use an arrow to indicate the direction of the acceleration (zero for no acc.). | **Acceleration**:Use an arrow to indicate the direction of the acceleration (zero for no acc). |  |
| N | **Sliding/No Motion**:Was the book moving relative to the paper Y/N? | **Walking/Sliding/No Motion**:Was the paper moving relative to the table (Y/N)? | Y |
| **FBD** book B: | **FBD** paper P: |
| In the boxes below, draw FBDs. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations**  | Newton’s 2nd Law **Equations**  |
| $$B:\sum\_{}^{}F\_{x}= = $$$$B:\sum\_{}^{}F\_{y}= = $$ | $$P:\sum\_{}^{}F\_{x}= = $$$$P:\sum\_{}^{}F\_{y}= = $$ |
| Rank all horizontal forces in terms of their magnitude and explain how you know (2nd and 3rd laws) |

Are your observations, FBDs and equations consistent?

**Case 2: Fast Pull** Place a book on a piece of paper and pull the paper **quickly** such that the book slides off the paper. Analyze the situation where the book is sliding on the paper but not yet in contact with the table. ***Neglect any friction between the paper and the table*.**

|  |  |
| --- | --- |
| **Book B**  | **Paper P** |
| **Observed motion Book B** | **Observed motion Paper P** |
|  | **Velocity**:Use an arrow to indicate the direction of motion for the book (zero for no motion). | **Velocity**:Use an arrow to indicate the direction of motion for the paper (zero for no motion). |  |
|  | **Acceleration**:Use an arrow to indicate the direction of the acceleration (zero for no acc.). | **Acceleration**:Use an arrow to indicate the direction of the acceleration (zero for no acc). |  |
| Y | **Sliding/No Motion**:Was the book moving relative to the paper Y/N? | **Walking/Sliding/No Motion**:Was the paper moving relative to the table (Y/N)? | Y |
| **FBD** book B: | **FBD** paper P: |
| In the boxes below, draw FBDs. Draw neatly, use a straight edge, include double subscripts on ALL forces, include a coordinate system, don’t invent forces. Lengths of arrows indicate magnitude of force. Mark action-reaction pairs of forces. |
|  |  |
| Newton’s 2nd Law **Equations**  | Newton’s 2nd Law **Equations**  |
| $$B:\sum\_{}^{}F\_{x}= = $$$$B:\sum\_{}^{}F\_{y}= = $$ | $$P:\sum\_{}^{}F\_{x}= = $$$$P:\sum\_{}^{}F\_{y}= = $$ |
| Rank all horizontal forces in terms of their magnitude and explain how you know (N2 or N3) |

Are your observations, FBDs and equations consistent?

**Part 4: Measuring the G’s in an Elevator**

Go to the elevator with your group, a spring bathroom scale, and a force plate. One person in the group will ride the elevator one time on the scale and a second time on the force plate. During the first ride, the others will read the bathroom scale and write down the data. During the second ride, they will record the data with the data logger and laptop. Before going to the elevator, ask me to show you how to set up the equipment.

You will be interested in the following motions:

1. not moving -
2. Up & starting -
3. Up & going -
4. Up & stopping -
5. Down & starting -
6. Down & going -
7. Down & stopping -

**DATA:**

During the first run, record the bathroom scale readings in the table on the next page. These readings will be very crude (do your best). Include units, convert to Newtons (not pounds).

During the second run, record with the data logger and laptop. Save the file on your thumbdrive.

**Analysis:**

Attach a BIG plot of your trip up and trip down. In your graph, indicate where each of the above motions is happening.

Use LoggerPro to estimate the force plate reading for each motion. Show your work in the attached graph. Add your force estimates to the table on the next page.

Draw a free body diagram of the person riding the scale in each situation and write down the corresponding N2 equation. Note: forces don’t need subscripts.

Calculate the magnitude and direction of the acceleration in each situation.

Person’s mass and weight:

In your attached printout, show how you use the force plate reading to find the person’s weight and mass.

Person’s weight (N): \_\_\_\_\_\_\_\_\_\_\_\_ Person’s mass (kg): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Motion | FBD (show relative length) | Newton’s 2nd Law Eq. | Reading Bathroom Scale | Reading Force Plate | acc. a(magn & direction) | Is everything consistent?Y/N |
| Not moving |  |  |  |  |  |  |
| Up & Starting |  |  |  |  |  |  |
| Up & Going |  |  |  |  |  |  |
| Up & Stopping |  |  |  |  |  |  |
| Down & Starting |  |  |  |  |  |  |
| Down & Going |  |  |  |  |  |  |
| Down & Stopping |  |  |  |  |  |  |

 **Part 5: Fun with Balloons**

**(to do outside of the lab hours)**

1. Obtain from your local physics department a helium balloon
2. I recommend that you do the experiment on a bus. You can also do it in a car with all of its windows closed. But if you do it in a car, the driver should not be the person doing the experiment. You must make sure that the balloon doesn’t interfere with the driving of the car and that all safety rules are observed (seat belts, etc…). An empty parking lot would be best to do the experiment in a car.
3. Write down how the balloon reacts to the following situations:
4. Speed up fairly quickly.
5. Slow down fairly quickly.
6. Turn to the right in a circle.
7. Turn to the left in a circle.
8. Write a paragraph which describes the results of your experiment and explains in terms of Newton’s first, second laws and air pressure differences why the balloon reacts as it does.