Topic 4: Dynamics – Force, Newton's Three Laws, and Friction

Source: *Conceptual Physics* textbook and laboratory book plus the CPO textbook and laboratory book

Types of Materials: Textbooks, laboratory manuals, demonstration, worksheets and activities

Building on: Once the student has worked with motion from the previous topic of kinematics, velocity and acceleration has been introduced. This now allows for the study of the cause of motion, force. A series of labs shows the student Newton's 2nd law and its specifics. First, the student discovers that a constant force produces constant acceleration. Secondly, the student discovers that acceleration is directly proportional to the net force and inversely proportional to a body mass. Also, labs showing Newton's 1st and 3rd law need to be performed. After understanding Newton's laws, the topic of the conservation of work and energy is explored. Friction is so much of a real thing that it cannot be ignored; thus it will be studied. When considering net force, friction must be included to confirm that acceleration is directly proportional to the net force.

Leading to: Once kinematics and dynamics have been studied, the student can then study the conservation of energy, the conservation of momentum and the conservation of angular momentum (for older students, probably not for freshman).

Links to Physics: After the study of kinematics and dynamics, centripetal force and circular motion including satellite motion can be explored. Dynamics explains why small cars can be powered by a 4-cylinder engine and a large truck will probably have a V8 for power. The aerospace industry needs to totally understand dynamics to put satellites in orbit or send people to the moon. High-energy physics needs to apply dynamics as modified by relativity principles to accelerate charged particles down the various accelerators. All industries need to understand dynamics to some degree, such as in building trades for constructing the house structure.

Links to Chemistry: Force and Newton's laws are discussed when comparing mass and weight. Weight on different planets may also be discussed to help explain the difference between mass and weight. Force per unit area (pressure) frequently is covered in chemistry when discussing air pressure and gases. In regard to properties of matter, friction is a topic that arises.

Links to Biology: The motion of a humming bird, the movement of a snake, the forces within muscles in the human body for contraction and extension are some examples of dynamics within living systems. Force can be taught in biology class when discussing the heart and blood flow. The blood can exert a force on the blood vessels—blood pressure. Conceptually, the harder the force is, the higher the blood pressure. The build-up of plaque will decrease the cross section of the vessel and lead to a higher pressure. One can even discuss fluid mechanics at this time. Other examples of force are the force that a root or earthworm must exert on soil to move the soil or the force that an embryo must exert to break out of a seed coat or animal to break out of an egg.

Materials:

(a) Hewitt
1. Lab 8 – Going Nuts
2. Lab 9 – Buckle Up
3. Lab 10 – 24-Hour Towing Service
4. Lab 11 – Getting Pushy
5. Lab 12 – Constant Force and Changing Mass
6. Lab 13 – Constant Mass and Changing Force

(b) Hsu
1. Lab 2A – Law of Inertia
2. Lab 2B – Newton's 2nd Law

(c) My Labs
1. Constant Force Produces Constant Acceleration
2. Constant Mass, Vary Force, Measure "a"
3. Constant Force, Vary Mass, Measure "a"
4. Friction

(d) Worksheets
Newton's Law Questions and Problems

(e) Demonstrations
Newton's 1st Law
1. Toilet Paper Pull
2. Cart and Figure with/without Seatbelt
3. Coin into Cup

Newton's 2nd Law
1. Change Mass of Cart being Pulled by Same Force
2. Change Force on Same Cart

Newton's 3rd Law
1. Skateboard, Student and Wall
2. Fan Cart on Desk
3. 2 Skateboards, 2 Students

(f) Websites and Videos

1. ESPN SportsFigures "That Mu You Do" Video Guide (NASCAR Racing)
2. Forces in 1-Dimension Lab Sim (Java)
3. The Ramp Lab Sim (2-D) (Java)
4. www.nextvista.org/tag/newton9627s-law
   (Demo with eggs; demo with rest and moving objects)

(g) Good Stories

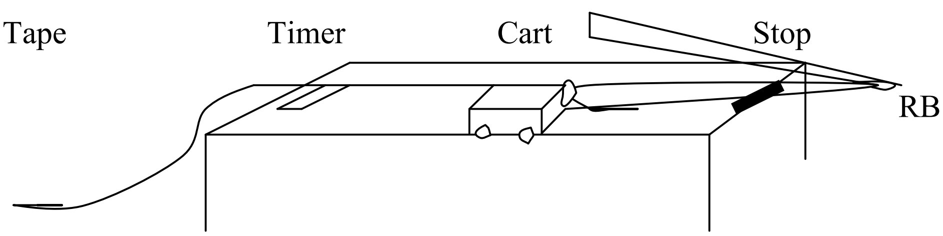
1. The Wrath of Newton
2. Newton's Birthday

Topic 4: C-1 – Constant Force Lab

Purpose: To see the effect of a constant applied force to a body has on its motion.

Equipment: Dynamics cart
Ticker timer with power supply and carbon paper
Ticker tape
One rubber band (about 6" long – available through Cenco, Sargent-Welch, etc.)
Level horizontal table
Meter stick
Bumper with C clamps to stop the cart at the end of the table

Drawing:



Procedure:

1. Get the timer functioning well. Thread the ticker tape through the timer and attach to the cart.
2. With the cart starting near the timer and at rest, pull the tape tight and attach the rubber band to the peg on the cart and the other end of the RB to the end of the meter stick.
3. With only the rubber band pulling (hands off), keep the rubber band stretched the SAME AMOUNT (maybe 10 cm-20 cm). Keep this EQUAL FORCE applied to the cart as you pull the cart across the table to the stop. The timer should be running to put dots on the tape.
4. Choose a dot on the tape near, but not at the start of motion, and count all the dots until the cart strikes the stop.
5. Depending on the number of dots, divide the tape into 5 to 10 equal TIME intervals (rounding will likely occur). As an example, if you count 62 dots across the tape and you divide the total interval into 10 equal times, 62 divided by 10 = 6 equal time intervals.
6. Measure the length of each interval and put these values into a table.
7. To make life easy, let each interval be 1 s. Divide each interval distance by 1s and record these average velocities in your table.
8. Record the total time in your table. For the example data, times of 1 s, 2 s, 3 s, 4 s, 5 s, and 6 s would be recorded.
9. Now calculate the CHANGE in velocity between each interval and record. Lets say one interval average velocity is 4 cm/s from 1 s to 2 s and 7 cm/s from 2 s to 3 s, so the

CHANGE in velocity is 3 cm/s between 1.5 s and 2.5 s (the change in time is 1 s). Therefore, 3 cm/s divided by 1 s equals 3 cm/s/s acceleration.

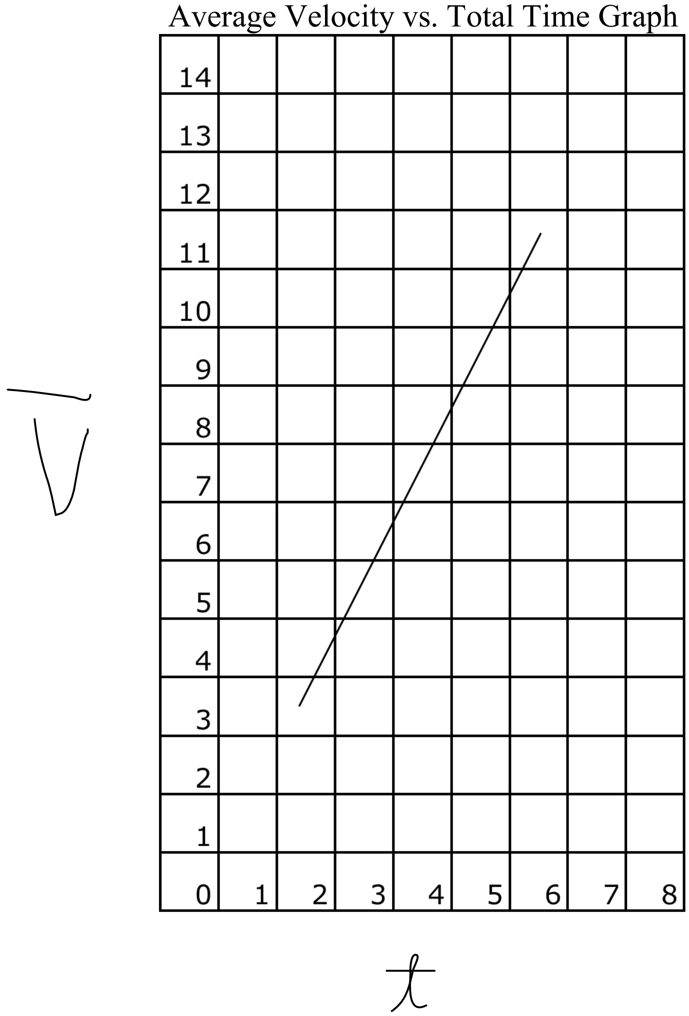
10. Draw and plot an average velocity vs. total time graph and state your conclusion about the motion when a constant force is applied to a body.

Topic 4: C-1 – Constant Force Lab Answer Sheet

For the Made-up Data Given:

Interval Distance (cm)	Interval Average Velocity (cm/s)	Change in Average Velocity (cm/s)	Total Time (s)
1	1		1
4	4	3	2
9	9	5	3
16	16	7	4
25	25	9	5
36	36	11	6

Average Velocity vs. Total Time Graph



This graph is linear showing that the change in velocity in a given amount of time is constant. Since the change in velocity divided by the change in time is constant, this is the definition of acceleration; so

A CONSTANT FORCE PRODUCES CONSTANT ACCELERATION.

For This Made-up Data:

$$a = (11 \text{ cm/s} - 3 \text{ cm/s}) / (6 \text{ s} - 2 \text{ s}) = 8/4 = 2 \text{ cm/s/s}$$

Topic 4: C-2 – Newton and Acceleration

Title: Acceleration of a constant mass with a variable force

Purpose: To determine how the acceleration of the same mass is affected when the applied force is varied.

Theory: Lab C-1 showed that a constant force produces a constant acceleration on a constant mass. Now, asking the question of how does the size of the force affect the acceleration of a constant mass, one can intuitively predict that a huge force will make a mass accelerate faster than a small force. However, is the relationship linear? Taking data in this lab will answer the relationship question.

Procedure:

1. Find two long rubber bands as used in Lab C-1 that nearly exert the same force on a spring scale when stretched the same amount.

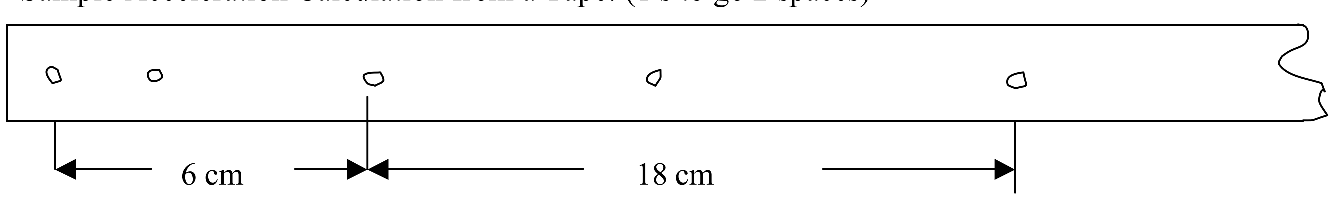
2. Using trial and error, find a force that produces a small visual acceleration. Measure that force with a spring scale calibrated in Newtons and record in Newtons (for example, let's say the force is 2.0 N). Pull the ticker tape as in Lab C-1, record the force in a table; calculate the acceleration and record in a table. You might find it easier if the cart is always loaded with about 2 kg.

3. Using one or two rubber bands, exert a stretch that doubles the force in procedure 2 and repeat procedure 2.

4. Repeat procedure 2 with three times the force, four times the force and if humanly possible, five times the force. For these greater forces, be sure to check the "stop" as you go to prevent injury! Record the forces and the calculated accelerations in the table.

5. Plot acceleration vs. force graph and compare the shape of the graph to known mathematical relationship shapes and state your conclusion.

Sample Acceleration Calculation from a Tape: (1 s to go 2 spaces)

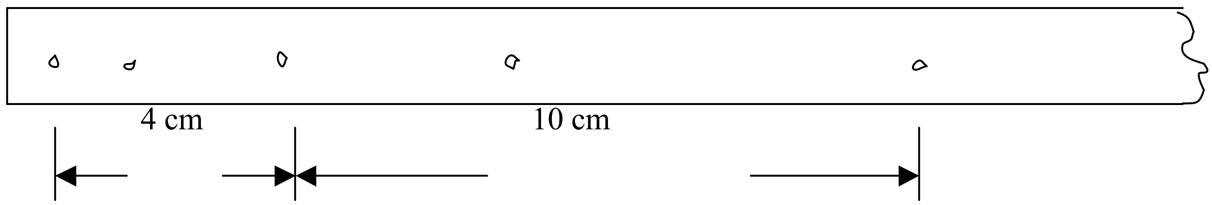


So, a = (18 cm/1 s – 6 cm/1 s) / (1.5 s - 0.5 s) = 12 cm/s/s.

Topic 4: C2 – Newton/Acceleration Answer Sheet

Question: How does the acceleration of a constant mass depend on the applied force?

Sample Data from Ticker Tape:
Smallest Force

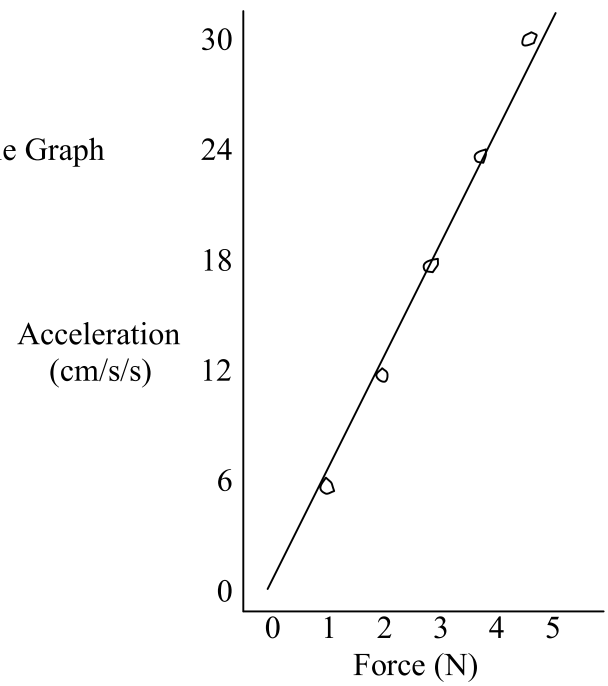


Let the time to go 4 cm be 1 s; let the time to go 10 cm be 1 s

so, $a = (v_f - v_i) / (t_f - t_i) = (10\ cm/s - 4\ cm/s) / (1.5\ s - 0.5\ s) = 6\ cm/s/s$.

At 2X the force, a = 12 cm/s/s.
At 3X the force, a = 18 cm/s/s.
At 4X the force, a = 24 cm/s/s.
At 5X the force, a = 30 cm/s/s.

Sample Graph



For a real graph with friction, the graph above will be shifted to the right but still parallel to the solid linear graph both showing a linear relationship between "a" and "F." Or, $a \propto F$.

Topic 4: C-3 – Newton – Mass and Acceleration Relationship

Title: Acceleration of Different Masses Using the Same Force

Purpose: To determine how acceleration is related to different masses when the force is the same. Assume the force is always greater than friction.

Theory: Labs C-1 and C-2 have shown that a constant force produces constant acceleration on a given mass and the acceleration of a body is directly related to the applied force. Now we will investigate the relationship between the acceleration of a body and the body's mass. To do this we will keep the same force on larger and larger masses.

Procedure:

1. Using the same procedure as in Lab C-1, pull the dynamics cart with one or two rubber bands at a very quick acceleration while keeping the force constant. Calculate the acceleration using the procedure as in C-2. Record.

2. Add 1 kg and repeat procedure 1. Add 2 kg and repeat procedure 1. Also repeat for 3 kg, 4 kg, and 5 kg. Mass the cart in kg.

3. For each ticker tape pulled, 1 kg, 2 kg, 3 kg, 4 kg, 5 kg added to the cart, calculate the acceleration of the cart.

4. Plot a graph of the acceleration of the cart as a function of the added mass (just the added mass—not with the cart).

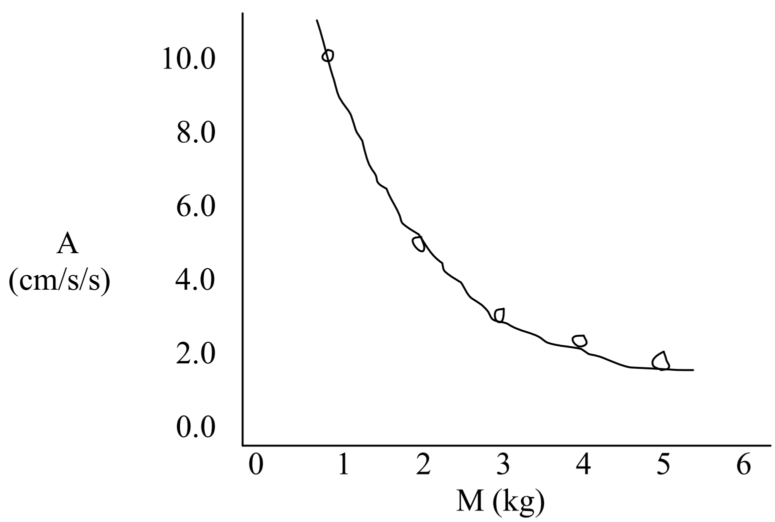
5. What is the relationship between the acceleration of a mass and its mass when using a constant force?

6. Combine the results of Topic 4, Lab C-2 and this lab, C-3, to form an equation.

Topic 4: C-3 – Newton – Mass and Acceleration Relationship Answer Sheet

Sample Data: Constant Force
Cart Mass = 1 kg

Added Mass (kg)	Total Mass of Cart and Added Mass (kg)	Acceleration (cm/s/s)
1	2	10.0
2	3	5.0
3	4	3.3
4	5	2.5
5	6	2.0



These curves show an inverse relationship, or, a $\propto$ 1/m.

A check on the inverse relationship can be done if a times m equals a constant.
This sample data shows:

1 x 10 = 10
2 x 5.0 = 10
3 x 3.3 = 10
4 x 2.5 = 10
5 x 2.0 = 10

The constant 10 for these sample data points shows an inverse relationship.

6. Since $a \propto F$ (C-2) and $a \propto 1/M$ (C-3), combining gives $a \propto F/M$; thus, $a = (\text{constant}) F/M$.

   The constant turns out to be 1 due to definitions of units, so

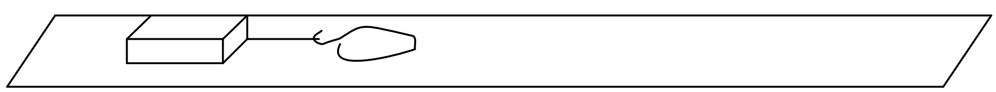
$$a = F/M \text{ or } F = MA \qquad \text{Newton's 2nd Law!!!}$$

Topic 4: C-4 – Friction

Purpose: To find the relationship between the forces that pushes two surfaces together and the friction that results.

Theory: As many people know, during the snowy winter, car drivers of rear drive cars put weight in their trunk to gain traction. In this activity, the relationship between the weight of the back of the car and the traction will be explored. The term for the push of the back wheels against the ground is the normal force because it is perpendicular. The term for traction is friction. One can think of the force pushing the two surfaces together as the normal force, but the upward force of the road pushing up is defined as the normal force. The two surfaces for this example are the road surface and the tires.

In this activity, the normal force (F_N) is numerically equal to the weight of a block of wood and what is placed on top of the wood. The friction (F_r) will equal the pulling force of a spring scale if the speed of the block is constant. The two surfaces are wood on wood. When the block is propelled forward with a force that results in constant speed, the opposing friction force matches the pulling force, so F(net) = 0. Recall that F(net) = ma, so when F(net) = 0, a = 0.



Draw and label the weight (W) of the block on the sketch. Also draw and label the normal force (F_N), the applied force (F_A) and the friction (F_r).

Materials: Any two materials can be used, but for this lab, wood on wood is the choice. Cut a 2" x 4" block about 6" long and insert an eyehook in the center of one end. Use a 1" x 6" board about 6' long for the flat horizontal surface. A spring scale that reads up to 20 N is used to pull the 6" block across the board. Use a loop of string to use between the block and spring scale to be more convenient. Five one-kilogram interlocking weights will be needed.

Procedure:

1. Weigh the block of wood in Newtons. Record.

2. Place the block at one end of the horizontal board. Attach the cord and spring scale to the eyehook. Zero the spring scale.

3. Add 1 kg to the block. Pull horizontally on the block with a constant speed across the board. Read the scale while moving. Record. How does the pulling force compare to the opposing frictional force?

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4. Repeat procedure 3, but with 2 kg aboard, 3 kg, 4 kg, and 5 kg aboard. Record these forces.

5. In your data table, make a new column for the added weights and the weight of the block. How does the total downward force compare to the upward normal force?

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6. Plot a graph of the frictional force (F_r) as a function of the normal force (F_N).

7. What is the shape of the graph? What is the math relationship between F_r and F_N?

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8. Is the slope constant or varying?

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9. What is the value of the slope of the graph? Compare your value with a textbook value. What is the meaning of this slope?

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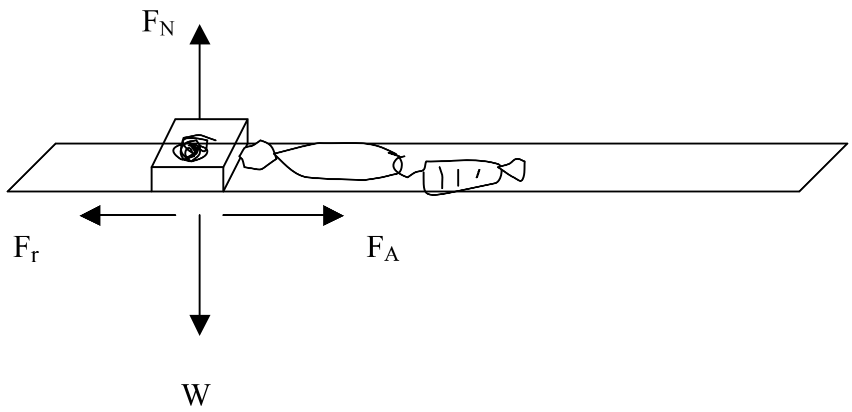
Other Optional Items to Check:

1. Pull at different constant speeds (slow and fast) to see what, if any, affect speed has on friction.
2. Do different materials: cloth on wood, metal on metal, etc., to see what affect this has on friction.
3. Compare starting friction to moving friction by comparing the pulling forces.
4. See if surface area changes the friction (in this activity, turning the block on its side would halve the surface area, thus a 2 to 1 ratio).
5. Try at hot and cold conditions.

Topic 4: C-4 – Friction Activity Answer Sheet

Drawing:



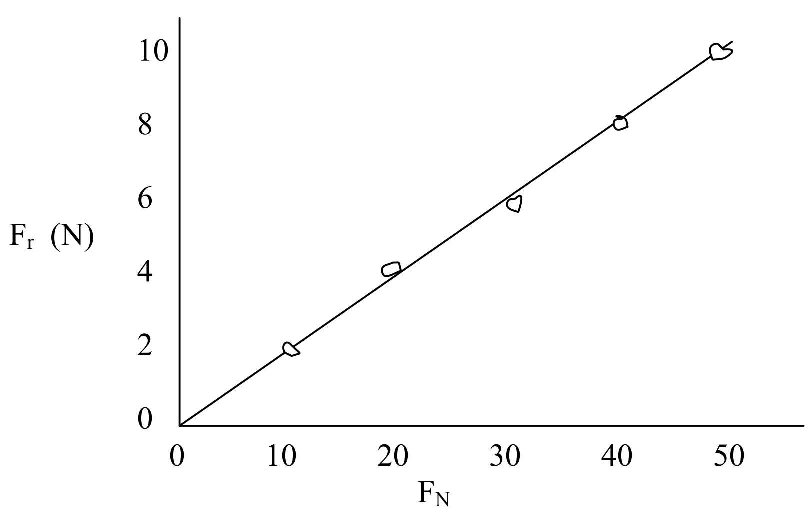
Reasonable Sample Data:
Weight of Board = 1.0 N

Added Weight (N) W	Normal Force including Block (N) F_N	Applied Force, also Friction (N) F_r
9.8	10.8	2.2
19.6	20.6	4.2
29.4	30.4	6.1
39.2	40.2	8.0
49.0	50.0	10.0

3. Pulling force = Frictional force, or $F_A = F_r$

5. Same, $F_D = F_N$ (up)

6.



7. Slope is a straight line, or the curve is linear. This is a direct proportion.

Direct proportion exists between F_r and F_N, or $F_r \propto F_N$.

8. Slope is constant.

9. Slope is called mu (Greek symbol) and written as: μ

$\mu = F_r / F_N = (10 - 0) / (50 - 0)$ N/N = 0.2 (no unit)

0.2 for wood on wood is about correct. (See tables in textbooks.)

The ratio, mu, describes the amount of friction that would exist between two substances. If mu is large, large friction; if mu is small, small friction.

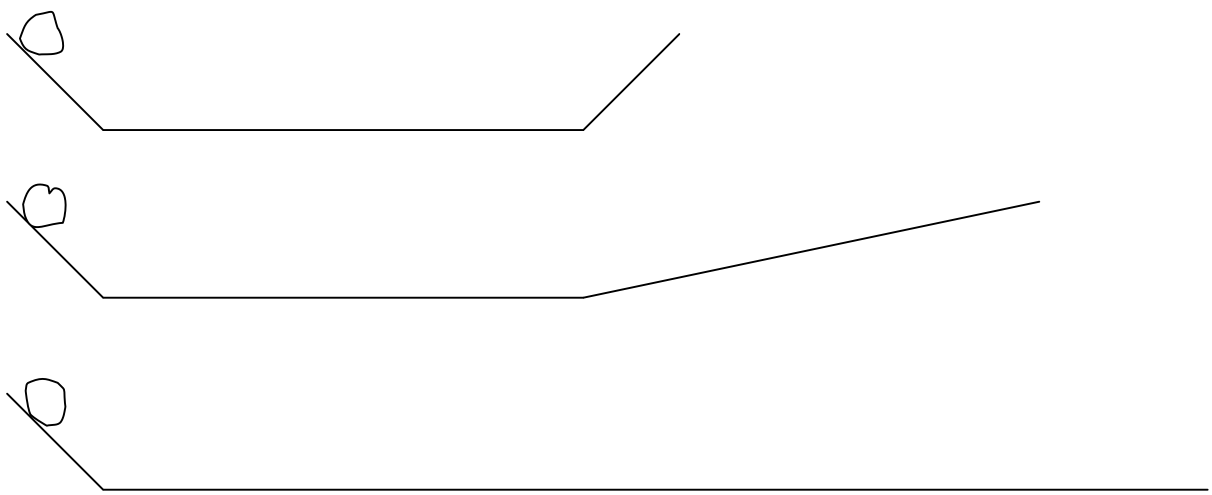
Optional:

1. Mu is the same at all speeds.
2. Yes, materials do matter: ice on ice will be small; rubber on concrete is large.
3. Starting friction is greater than moving friction, so mu is larger for static friction.
4. Surface area has no affect on mu.
5. Temperature has no affect on mu.

Topic 4: D-1 – Newton's Law Worksheet (Questions and Problems)

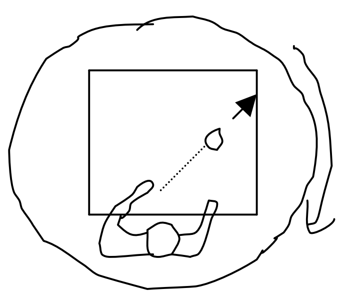
Newton's 1st Law:

1. Galileo revisited: Around 1650, Galileo sketched three ramps as shown below and asked how far up the other side of the ramp the ball would roll if no friction was present and the ball was released from rest.



   What is your answer for each of the sketches and why?

2. A table and chair with a student are mounted on a platform that is rotated at a constant rate. The table has a frictionless top, and the student propels a frictionless puck at a 45-degree angle to the table (see the sketch).



   You are mounted to the ceiling and looking down.
   Describe what you would see.

3. Why can't you walk if you were on totally frictionless ice?

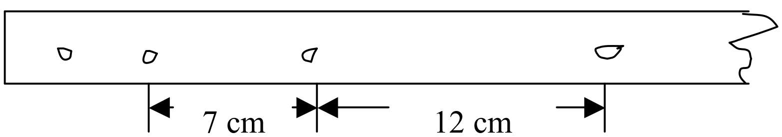
4. Why does a truck in the parking lot just stay there and not move?

5. Why does a truck flying down a road at a high rate of speed have so much trouble stopping quickly?

6. A ball is thrown parallel to the ground by a student. The first Newton law says the ball will continue in a straight line, but it doesn't. Why not?

Newton 2nd Law:

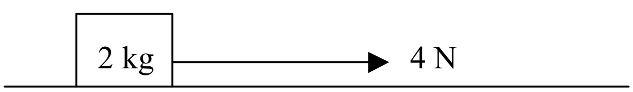
1. If a net force gets larger on an accelerating mass, how will the mass respond?
2. If a truck loaded with bricks is accelerating, but many bricks fall off during acceleration, what will now happen to the motion of the truck?
3. Name the math relationship between acceleration and net force on a mass.
4. Name the math relationship between acceleration of a mass and the mass.
5. If a rocket blasts off from earth and proceeds on its way to the moon, what would happen to the rocket's acceleration if you assume the rocket continues to exert the same thrust? Keep in mind that the rocket has a large percent of its mass as fuel. Ask yourself what happens to gravity as the rocket leaves the earth.
6. The same force is applied to mass A and mass B. Mass A at 40 kg accelerated at 40 cm/s/s and mass B accelerated at 20 cm/s/s. What is the mass of B?
7. A force acts on mass A giving it an a = 5 cm/s/s; the same force causes an a = 15 cm/s/s on mass B. What is the ratio of mass A to mass B?
8. How long would it take a constant 10 N force to cause 5 kg to accelerate from rest to 20 m/s?
9.



2 s between dots

How big of constant force causes a 2 kg mass to accelerate as shown?

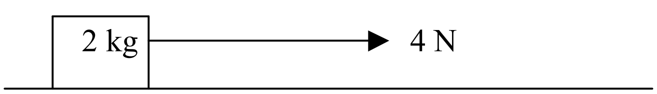
10.



Calculate "a."

No friction

11.



Calculate "a."

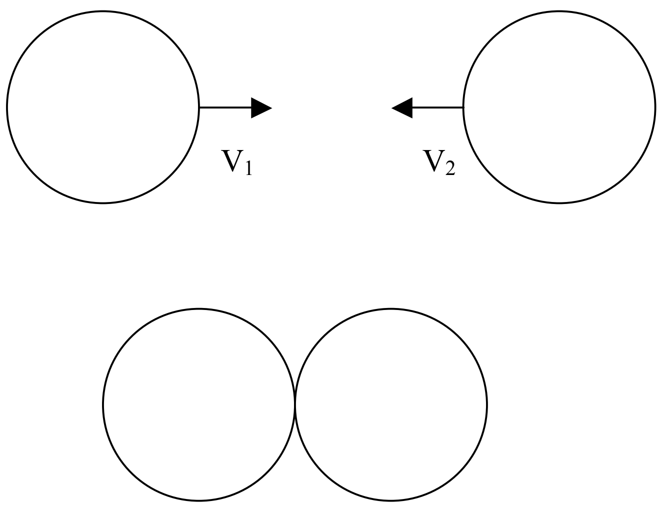
1 N of friction

Newton's 3rd Law:

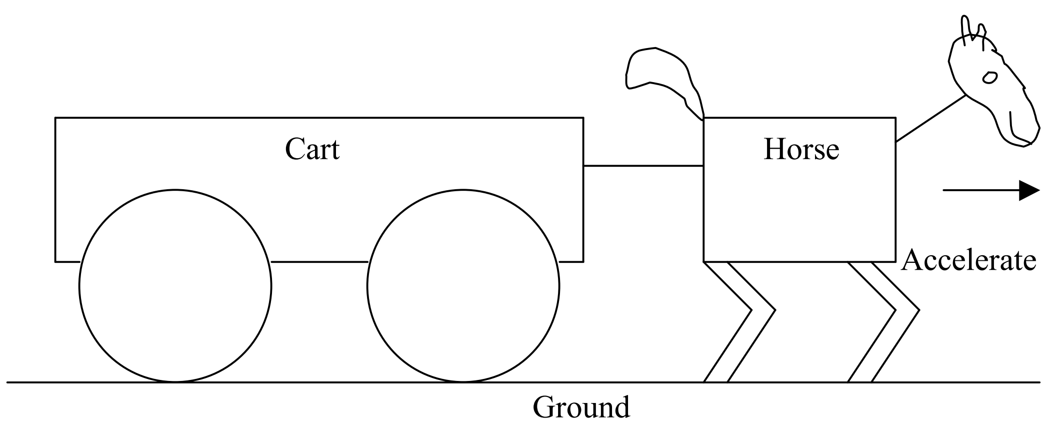
1. What is the reason when you push on a wall while standing on a skateboard that you accelerate away from the wall? Doesn't the force of you on the wall equal the force the wall exerts on you, and shouldn't they cancel out?

2. Why can you walk on pavement?

3. Two equal mass spheres move toward each other at equal speeds. At contact, draw the forces on the spheres and label them $F_{1,2}$ and $F_{2,1}$; ($F_{1,2}$ means mass one pushes on mass 2.) How do the forces compare?



4.



(a) How many Newton 3rd law PAIRS of forces are acting on the horse, ground and cart as the horse/cart accelerate? Identify each.

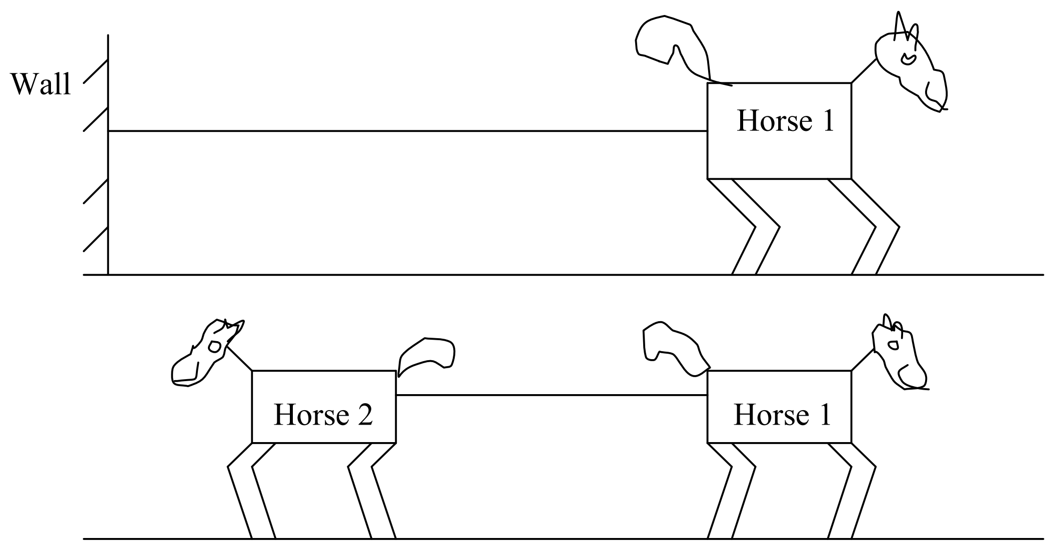
(b) Which pair is the largest?

(c) Which pair is the smallest?

(d) Does the horse push forward or backward to accelerate the horse forward?

(e) Does the ground return the horizontal push on the horse? Compare the size of these two forces. Do they cancel out? Why or why not?

5.

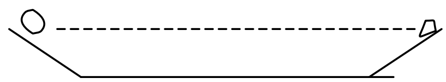


(a) Horse 1 pulls on a wall. The wall and horse don't move, but a lot of tension exists in the rope. Does the horse feel the same force as what is within the rope? How big is the force on the wall?

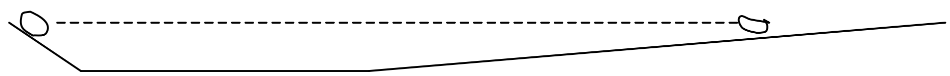
(b) The same horse 1 is attached to identical twin, horse 2; with a rope they pull. Compare the rope tension now to when horse 1 was pulling on the wall.

Topic 4: D-1 – Newton’s Law Worksheet (Questions and Problems) Answer Sheet

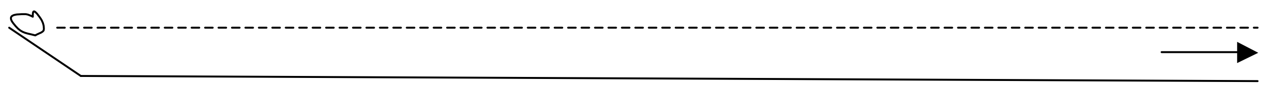
Newton’s 1st Law:

1. 

Same height; ball repeats same motion—symmetry; easier to explain with energy topic.



Same height, same reason.



Go forever. No reason to stop since no friction. A body in motion goes forever in a straight line with no external force. Galileo did these very experiments with a hard wood, waxed ball and waxed boards and could see his ideas were correct.

2. You would see the puck go in a straight line and the table would appear to rotate in a circular path beneath the ball. If you were in the frame of reference of the table/student, the puck would travel in a circle.

3. You cannot push back on the ice, so the ice can’t propel you forward.

4. Since the truck has no horizontal force on it, a body at rest remains at rest.

5. A body in motion stays in motion—inertia (mass) too large. Momentum and energy will later explain this phenomenon.

6. An external force, in this case gravity, acts down on the ball causing it to curve downward. The shape is a parabola.

Newton’s 2nd Law:

1. Since $a \propto F$, a direct relationship exists; so when F increases, so does acceleration.

2. When bricks fall off the truck, the mass decreases, so the acceleration increases with a constant force.

3. Direct relationship

4. Inverse relationship

5. Since fuel is used up, the rocket's mass decreases causing an increase in acceleration. Likewise, the further away from the earth the rocket goes, the smaller the gravity force, so again, faster acceleration.

6. $a \propto m$ and $F = MA$, so $M_A A_A = M_B A_B$

   Or,

   $(40 \text{ kg})(40 \text{ cm/s/s}) = M_B (20 \text{ cm/s/s})$, so $M_B = 80 \text{ kg}$

7. $a \propto 1/m$, so $M_A/M_B = A_B/A_A$

   $M_A/M_B = (15 \text{ cm/s/s}) / (5 \text{ cm/s/s}) = 3/1$ or 3

8. $F = MA$; $F = (M)(\Delta V) / (\Delta t)$; $(10 \text{ N}) = (5 \text{ kg})(20 \text{ m/s} - 0) / (\Delta t)$; $\Delta t = 10 \text{ s}$

9. First, $a = (\Delta v) / (\Delta t)$; $a = (12 \text{ cm}/2 \text{ s} - 7 \text{ cm}/2\text{s}) / 2 \text{ s} = (6 - 3.5) / 2 = 1.25 \text{ cm/s/s}$; then, $F = MA$; $F = (2 \text{ kg})(1.25 \text{ cm/s/s}) = 2.5 \text{ N}$

10. $A = F/M$; $A = (4 \text{ N}) / (2 \text{ kg}) = 2 \text{ m/s/s}$

11. $A = F/M$; $A = (4 \text{ N} - 1 \text{ N}) / (2 \text{ kg}) = 1.5 \text{ m/s/s}$

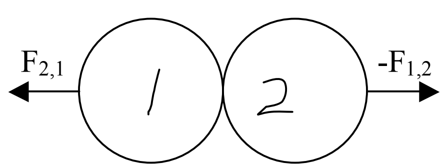
Newton's 3rd Law:

1. Reaction. When you push on the wall, the wall pushes back on you with an equal but opposite force that causes your acceleration, $a \propto F$.

   Yes, the forces are equal, but, no, the forces act on different bodies. You feel one force of the wall.

2. Friction. You push back on the pavement and it pushes forward on you (action-reaction).

3.



$F_{2,1} = -F_{1,2}$ equal and opposite

4. (a) 3 pairs:
   1. Horse-ground (F horizontal)
   2. Horse-cart (F horizontal)
   3. Cart-ground (F horizontal)

(b) Horse-ground
(c) Cart-ground
(d) Backward
(e) Yes; equal but oppositely directed; the force does NOT cancel because the horse feels one force and the ground feels the second force of the pair.

5. Yes; (F on horse = F on rope)
   (a) F on wall same as F on horse and same as F on rope
   (b) Same tension as when the horse pulled on the wall

Topic 4: E-1 – Dynamics Demonstrations

Newton's 1st Law: A body at rest will remain at rest if no outside force acts on it; a body in motion will continue in motion in a straight line if no outside force acts on it.

1. Toilet Paper Pull: If you place a dowel rod through the roll and pull slowly, the roll unwinds since it has time to accelerate. If you pull quickly, the individual squares tear off since the inertia of the roll is large and the time is too small for acceleration.

2. Cart and Figure with/without Seatbelt: Use the dynamics cart with a soft, unbreakable figure like an 8-inch-tall teddy bear riding on top. Get the cart and bear going by slowly accelerating them and smash them into a wall. The bear goes flying since—1st law! Repeat by strapping the bear (I use duct tape) down and the bear stays on the cart.

3. Coin into Cup: Place a 3" x 5" index card over a cup or beaker and place a coin like a quarter (larger mass) on the card. Flick the edge of the card horizontally quickly with your finger and the coin falls into the cup—1st law.

   (Be creative—the list of demos is limited by your imagination.)

Newton's 2nd Law: The acceleration of a mass is directly related to the applied net (total) force acting on the mass and inversely related to its inertial mass. A = F/M

1. Change mass of cart being pulled by same force. Like in the Newton lab, pull one dynamics cart with one rubber band so it accelerates quickly. Repeat using the same pulling force but put many kilograms on board to see a dramatic difference (NO numbers needed here).

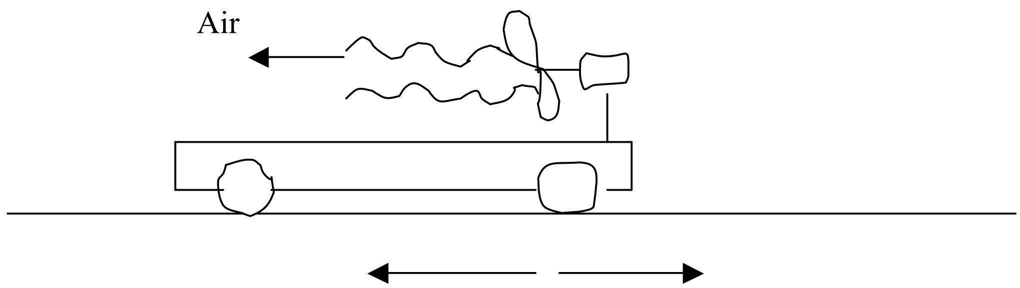
2. Pull one dynamics cart with one rubber band as in the lab so it accelerates slowly. Now pull the same cart but with two or more rubber bands so the same mass accelerates noticeably quickly. Practice is required to show conceptually the 2nd law.

Newton's 3rd Law: The 3rd law states that when one mass pushes on a second mass, the second mass pushes back with an equal force but in the opposite direction. Each body feels one force, so each body will accelerate, not cancel out the other force as some students would predict (action and reaction). Forces always occur in pairs.

1. First, you or a student (safer for you) stands on a skateboard at rest facing a wall and pushes off; the teacher/student accelerates nicely but the wall doesn't. Ask the why question to the students—why you accelerate but not the wall. The wall is attached to the school, so its mass is too large and since too much friction prevents the wall from accelerating, you will accelerate because the mass is small.

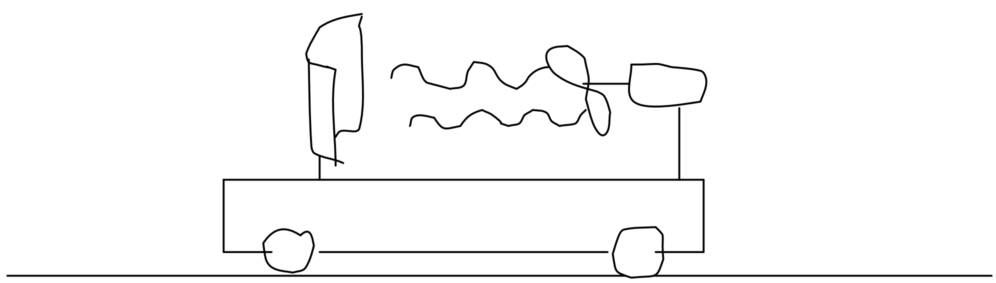
2. Use a commercial fan cart or mount a fan on a dynamics cart and ask if the cart

will move and in what direction. Most will get it correct and indicate the air goes one way but the cart goes the other—3rd law. However, ask to explain how this demo works in terms of pairs. The sketch below should help.

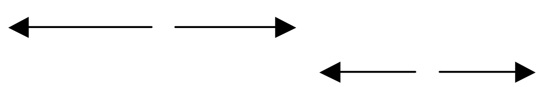


F fan on air = F air on fan

Now put a sail on the cart and ask if it will work. Also explain in terms of the pair of forces.



F air on sail = F sail on air F fan on air = F air on fan

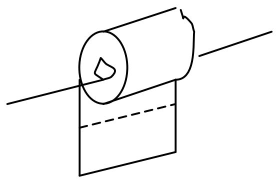


Since F sail on air and F fan on air are equal, then, the F air on sail and F air on fan are equal. The sail and fan are both attached to the boat, so the net force on the boat is zero; thus, the boat stays at rest.

Topic 4: E-2 – Demonstrations of Newton's Three Laws

Newton's 1st Law:

1. Toilet Paper Pull



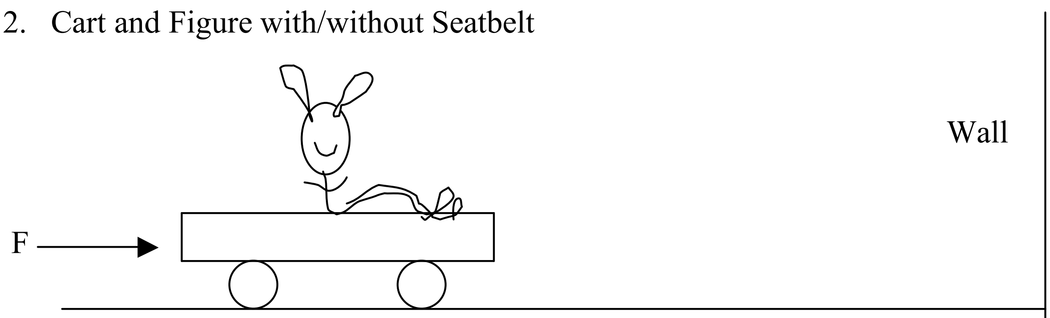
Place a full roll of toilet paper on a smaller dowel rod with little friction through the cardboard tube center.

(a) Try to remove 1 sheet when you pull slowly and down. Discuss. (Sheet probably won't tear off and will unroll the paper since the time of acceleration is long enough to not take advantage of the inertia of the mass.)

(b) Repeat (a), but pull down quickly.
(Will work due to the short time and thus larger force; the inertia of the mass allows you to remove 1 sheet.)

(c) Repeat (a) and (b), but using a nearly empty roll.
Repeat (a) result – One sheet won't tear because the force is too small as the time of acting is too long.
Repeat (b) result – Might work if you pull fast to make Δt small enough for F to be large enough.)

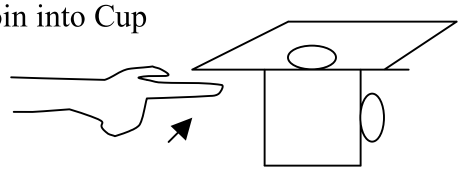
2. Cart and Figure with/without Seatbelt



(a) Roll a dynamics cart and stuffed toy of your choosing (rabbit shown) at a wall at high speed. Observe. (Toy flies into wall causing death; a body in motion stays in motion—inertia at work. The wall's force on the cart stops the cart.)

(b) Repeat (a) but put a seat belt on the toy (duct tape could be used). Observe. (Toy remains part of vehicle—seat belt GOOD! Can prevent death!)

3. Coin into Cup

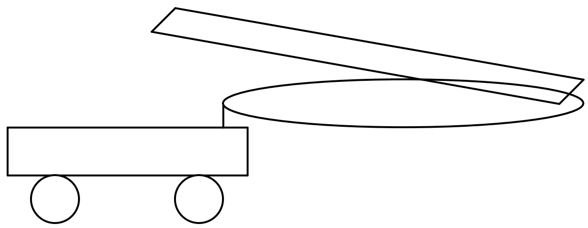


Place a coin on an index card above your coffee cup.

Quickly snap a corner of the index card with your finger. Observe. (The card goes flying and the coin drops into the cup; a body at rest stays at rest.)

Newton's 2nd Law:

1.



(a) Loop a long rubber band around a rod inserted into a dynamics cart and place a meter stick into the loop of the rubber band and stretch the rubber band as shown. The stretch should be such that the cart accelerates quickly but at a rate that allows you to maintain the same stretch.
(b) Repeat (a) with a brick atop the cart using the same rubber band and the same stretch. Observe any change.
(c) Repeat (a) with 2 bricks atop the cart. Observe.

(Students can easily observe that using the SAME FORCE on INCREASING MASSES results in DECREASING ACCELERATIONS. $A \propto 1/M$)

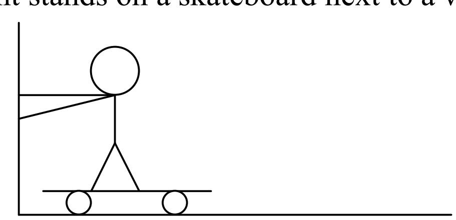
2.

(a) Use the procedure as in 1 with 1 brick on the cart but pull with a force that causes a small but noticeable acceleration.
(b) Again use one brick but use 2 identical rubber bands at the same stretch to accelerate the cart. Observe any change.
(c) Repeat with 3 rubber bands. Observe.

(Students will easily see that INCREASING THE FORCE CAUSES THE ACCELERATION TO INCREASE. $A \propto F$)

Newton's 3rd Law:

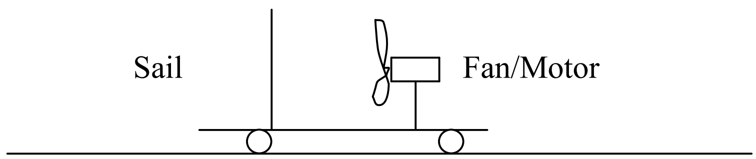
1. You or a coordinated student stands on a skateboard next to a wall.



The rider pushes off from the wall. Explain what took place.

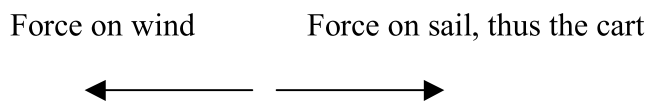
(This is a straightforward action-reaction example. Rider pushes the wall [action] and the wall pushes back with an equal but oppositely directed force [reaction].)

2. Use a cart from most scientific supply companies that has an electric fan/motor mounted to a lightweight low-friction cart.



(a) Ask students which way the cart will move (or not move) when NO SAIL is attached to the cart. Establish which way the wind blows as you hold the cart at rest and hold a sheet of paper in front of the sail. Have the students discuss what will happen before you turn on the fan. Turn on the fan.

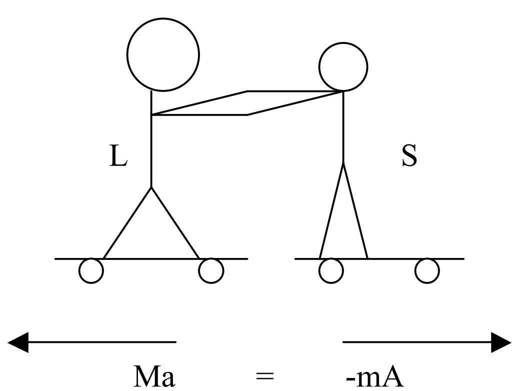
(In this sketch, the wind blows to the left so the cart goes to the right. This vector sketch should help.



The wind feels one force of the action-reaction pair and the cart feels the other ONE FORCE to the right, so it accelerates to the right.)

3. Have two coordinated students—one small and the other larger—stand on skateboards as shown. Ask what will happen as they push off from each other? So, 3, 2, 1, go and observe.

(Since $F_{S,L} = -F_{L,S}$ and $F = MA$, we get $Ma = -mA$, which shows the larger person has a smaller acceleration and the smaller person a larger acceleration.)



Newton's Two Birthdays

It is customary to celebrate the birthday of Isaac Newton on Christmas Day 1642. Newton was considerably premature at birth and was given little hope of survival. It was said that he was small that he could be fitted into a quart pot. Newton's father (also an Isaac) had died three months earlier, which left, Hannah, his mother, the task of raising the lad.

Today we can celebrate Newton's birthday twice, first on December 25 and on January 4. On the day of Sir Isaac's birth, it was December 25, 1642 only in England. For the rest of Europe it was already January 4, 1643.

Since the year 355 A.D., the Christian calendar had designated March 21 as the day of the vernal equinox. A solar year of 365 days, 5 hours, 48 minutes, 46 seconds is 11 minutes and 14 seconds short of a Julian calendar year. Over the course of more than 1200 years, the vernal equinox was off by more than 10 days occurring on March 11.

In 1582 Pope Gregory decided to set the calendar right. To restore March 21 as the vernal equinox, he declared that October 4 would be followed by October 15, thus adding 10 days to the Julian calendar. He also instituted a leap year, which was any year evenly divisible by 4, except centennial years evenly divisible by 400. This new Gregorian calendar is used throughout most of the Christian world today. So while England celebrated Newton's birthday on December 25, it was already January 4 in the rest of Europe and most of the world as well.

The Wrath of Newton

Sir Isaac Newton, for all his genius, was the epitome of strangeness. He was introvert, solitary and never seemed to smile. (An instance of Newton smiling is said to have taken place when a student asked him if there was any benefit to studying Euclid.) Sir Isaac was known to stare into space for hours on end as a rush of thoughts and ideas passed through his head. Newton was not a sociable person and had few, if any, friends. One of his character traits was the inability to give or share credit with those who may have contributed, even in the least way to his discoveries. One person who aroused Newton's anger was Robert Hooke. Hooke was not a second-rate scientist. He held the title of "Curator of Experiments" at the Royal Society and seemed to think that he deserved more credit than he was given. Hooke had several arguments with his contemporary scientists.

When Newton sent his completed manuscript of Book I of his Principia to the Royal Society, Hooke claimed that Newton had taken his idea from a dozen or more years before. Newton's contempt for Hooke escalated. Newton would not acknowledge any of Hooke's contributions, and there were many. Newton went through his manuscripts and deleted any references to Hooke. In spite, Newton threatened to suppress publication of Book III altogether. Still Sir Isaac continued his feud with Hooke. It seemed that Robert Hooke had made a permanent enemy. Newton kept Hooke as his whipping boy and refused to publish his "Optics" or accept the presidency of the Royal Society until Hooke had died in 1703.