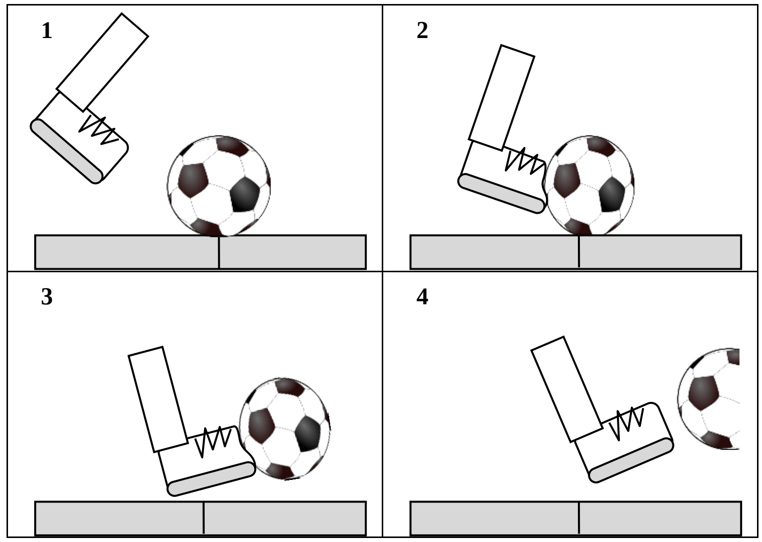
SPH3U: Interactions and Forces

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

When two objects affect one another in some way we say that they *interact*. Today we begin exploring the nature of these interactions and what happens as a result.

A: Thinking About Interactions

Watch the slow motion video of the foot kicking the ball. Refer to the frame numbers in the sketches to help answer the questions.



1. **Observe.** There is an interaction between the foot and the ball. In which frames is the interaction present?

2. **Observe.** What evidence is there (what do we <u>see</u>) that leads us to believe than the ball experiences an interaction? What about the foot?

The ball and foot interaction is an example of a *contact interaction*. Such an interaction is only noticeable when the two objects are in contact. When they are not in contact, there is no interaction.

3. **Reason.** Does the ball participate in any other contact interactions? In which frames and between which objects?

Non-contact interactions can take place even when the objects are not in contact: when the objects are separated by some distance, they still have an effect on one another. Note that an interaction always involves a **pair** of objects.

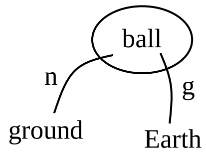
For the purpose of understanding interactions, we will think of and describe the ground and Earth as two separate objects since they often participate in interactions in different ways.

4. **Reason.** Does Earth participate in a non-contact interaction with the ball? Explain.

5. **Reason.** Does the ground participate in a *non-contact* interaction with the ball? Explain.

We can construct an *interaction diagram* (ID) to help represent the interactions present at some moment in time. An ID lists all the objects that are interacting with one another and has lines representing each interaction. The lines are labelled with a single letter describing the type of interaction: a = applied (a person's contact), g = gravitational, n = normal (surfaces in contact) and many more! There can be many, many interactions in a given situation so we need to narrow our focus by selecting a *system*: an object or collection of objects whose interactions we are interested in. We show the system objects by drawing a circle around them. We will usually leave out other interactions that don't involve the system objects.

6. **Represent.** In the chart below, complete the interaction diagrams for each of the four frames of the video. The ball is the system.

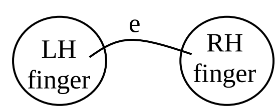
1	2	3	4
			

B: A Model Interaction

We are going to use an elastic band to examine an elastic interaction. **Each member** of your group should try this.

1. **Describe.** Loop one elastic band around your two pointer fingers. Separate your fingers until the elastic band has a good amount of stretch. Describe the effect the elastic has on **each** finger.

2. **Represent.** How does the pull of the elastic on each finger compare? Draw an arrow representing the force the elastic exerts on each finger. The arrow should **start** from each finger on the diagram. (Don't draw the elastic.)



Every interaction has two parts called *forces*. Intuitively, a force is a push or a pull of one object on another. In our previous example, we say the two fingers are interacting with one another through the elastic. The fingers pull on **each other**.

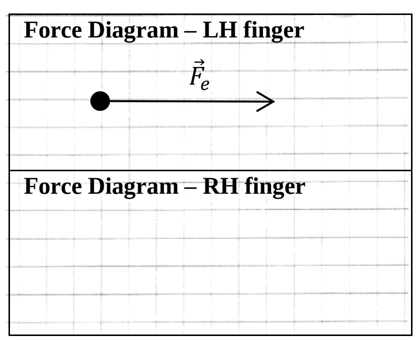
3. **Describe and Represent.** Rest your fingers and try again using the same elastic stretched to a **greater** distance than before. Describe how the sensation of force on your fingers has changed. Draw arrows again and explain how you chose to draw their **length**.

4. **Reason.** What type of quantity best represents a force: a scalar or a vector? Explain.

C: Representing Forces

We use a *force diagram* to model a system and represent the forces that the system experiences. In high school physics, we will always use the *point particle* assumption and imagine all the mass of the system objects compressed into a single point. For each interaction the system experiences, we draw a force vectors arrow that begins on the point particle. Label force vectors using a subscript showing the type of interaction (for example $\vec{F}_e$, an elastic force). Note that the arrow over top the force symbol does not show a direction, it just means "this is a vector".

1. **Reason.** Focus on the system of the left finger. According to the interaction diagram above, how many interactions does this finger experience? How many vector arrows should we draw on the force diagram?

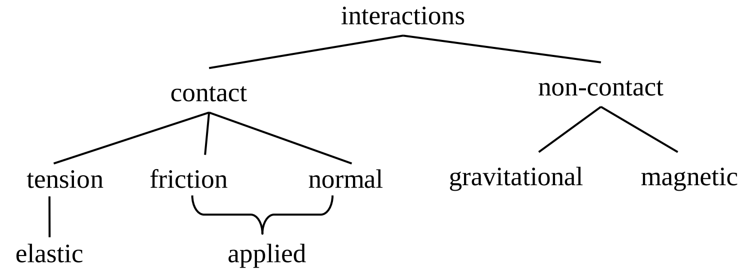


2. **Represent.** Now draw a force diagram for the system of the right hand finger hand. Explain how you choose to draw the length and direction of the force vector.

SPH3U Homework: Interactions   Name:

A: Interactions and Forces

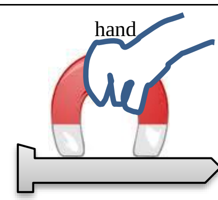
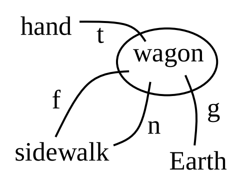
There are many different ways in which objects can interact and these different types of interactions can be organized into two large groups. Some common ones are listed below.



<u>Types of Interactions / Forces</u>

Tension (t) = two objects pulling on each other through a rope or string (no stretching)
Elastic (e) = two objects push/pull on each other due to stretch or compression of material
Friction (f) = resistance between two surfaces that are slipping or trying to slip past each other
Normal (n) = two surfaces in contact and pressing in to each other
Applied (a) = the contact force due to a person – a combination of friction and normal forces
Gravitational (g) = the gravitational interaction between two objects
Magnetic (m) = the magnetic interaction between two objects
Our contact interactions usually focus on solid objects. It is also possible to have a contact interaction with a fluid. One example of this is **air resistance** (a) or (air), and **buoyancy** (b) the interaction responsible for floating.

1. **Represent.** For each situation below complete the missing parts: the description (with the system), the sketch, or the interaction diagram.

Situation 1	Situation 2	Situation 3	Situation 4
A ball is attached to a string. Your hand holds the string steady. The ball does not move. system = ball	system = chocolate	system = nail	system =
			
			

2. **Reason.** In situation #1 above, your described the interactions for a ball and hand. To simplify our models, we often think of tension as an interaction between the two objects (hand and ball) that happens *through* the string. As a result, we won't show the string as a separate object in our interaction diagrams. If necessary, draw a new interaction diagram here to show this understanding of tension.

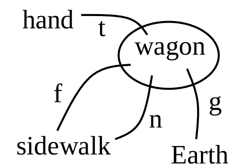
3. **Represent.** Draw a force diagram for situation #1 above. This is new for us, so just do your best to describe how you choose to draw the force vectors.

FD

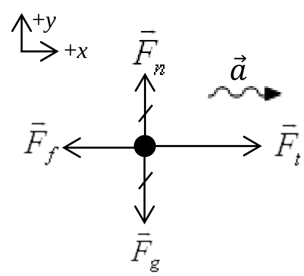
SPH3U: Forces Unit Rubrics

Use these rubrics to help assess the quality of your representations.

Interaction Diagrams

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Interaction diagram is constructed but contains many errors or a major error: • Missing or extra interactions (for the appropriate interval of time) • Missing or extra objects (for the appropriate interval of time)	Interaction diagram contains no major errors, but might have a few minor errors.	• The diagram contains all appropriate interactions and only the interacting objects. • System objects are enclosed in a shape (circle) • Each interaction is shown by one line (without arrows) connecting specific objects in the system or environment • Each interaction is labeled with a single letter (not a force symbol) • Each object's name is written only once	

Force Diagrams

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Force diagram is constructed but contains many errors or a major error: • Missing or extra forces (not matching with the interaction diagram) • Incorrect directions of arrows or incorrect relative length of force arrows.	Force diagram contains no major errors, but might have a few minor errors.	• The diagram is large, clear and has a coordinate system • It contains all appropriate forces and matches the interaction diagram. • Each force is labeled with a unique symbol that has a vector arrow. • 3rd law force notation ($F_{g\ e\text{-}b}$) is used if there are multiple systems or similar forces • Relative lengths of force arrows are correct, equal sized forces are shown with a "tick" mark. • Acceleration vector is drawn if appropriate.	

Newton's 2nd Law Expressions

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Expressions for Newton's 2nd Law are constructed but contain many errors or a major error: • missing or extra forces (not matching with the force diagram) • *x*- and *y*- forces are appear in wrong equation • one equation contains forces from both *x*- and *y*-directions	Force diagram contains no major errors, but might have a few minor errors.	• The process begins by writing the original 2nd law equation for each direction that has forces (i.e. $F_{net\ x} = ma_x$) • Each force is written with a unique force symbol and does not have a vector arrow symbol. • 3rd law force notation ($F_{g\ e\text{-}b}$) is used if there are multiple systems / similar forces • Direction of the force is shown using the sign convention. • If there is no acceleration, the equation equals zero.	$F_{net\ x} = ma_x$ $F_t - F_f = ma_x$ $F_{net\ y} = ma_y$ $F_n - F_g = 0$

Adapted from E. Etkina, *ISLE Laboratory Program*, https://sites.google.com/site/scientificabilities/rubrics

SPH3U: What is the Effect of a Force?

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

What happens when a single force acts on an object? This is a tricky question that took very clever people about 2000 years to figure out. Now it's your turn!

A: The Steady Pull

You need a dynamics cart and a 5-N spring scale.

We will use a spring scale to measure the size of forces. First you need to *calibrate* the spring scale. Hold the scale horizontally or vertically just as you will use it when measuring, but without pulling on it. Adjust the scale (a sliding cover or nut at the top) so it reads zero. The scale reads in units called *newtons* whose symbol is *N*.

1. **Test.** Practice exerting a **constant**, **horizontal** force (try around 1 N) on the dynamics cart. You should be able to do this for an interval of about four seconds. Practice this. When you are ready, call your teacher to witness your awesome technique.

2. **Reason.** To achieve a constant force, what must you observe about your spring scale?

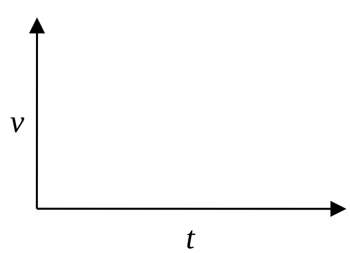
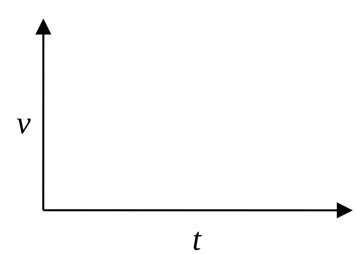
3. **Reason**. How does the cart move while it experiences the constant force? What are two possible guesses? Based on your observations, can you easily decide which guess might be correct?

B: On the Right Track

Your teacher has a cart set up on a track with a motion detector. Soon you will pull on the cart with a constant 1-N force.

A *hypothesis* is an idea that attempts to explain how something works. Once we have a hypothesis, we can use it to make a *prediction* about what might happen in a specific situation. A good prediction is detailed enough that we can use an experiment to test it. If the test shows that the prediction is not successful, the hypothesis is *refuted*. If the prediction is successful, our hypothesis is *supported* (it is strengthened and not yet refuted). We can never prove a hypothesis to be true!

1. **Predict.** People tend to have two hypotheses for this situation. Use each hypothesis to predict what the velocity graph for the cart should look like when the cart is pulled by a constant force.

Hypothesis A: When we exert a single, horizontal force on an object, it will move with a constant velocity.	**Hypothesis B**: When an object experiences a single, horizontal force, it will accelerate.
Prediction A 	**Prediction B** 

2. **Test and Evaluate.** Be sure to keep your force constant for as long as you can. Use the motion detector to track the cart's motion while you pull. Do your measurements support or refute the two hypotheses?

3. **Represent and Reason.** Draw an interaction diagram for the system of the cart while you exerted a constant force on it. Which of these interactions has a force that acts in the horizontal direction? Today, we are focusing on the horizontal forces acting our objects.

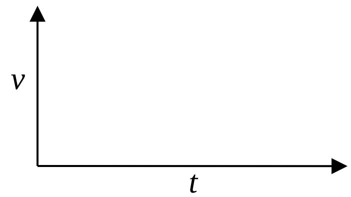
ID

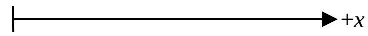
4. **Apply.** Isaac is in a store, pushing a shopping cart along the aisle. He says, “Look, I’m exerting a single force on the shopping cart and it is moving with a constant velocity. This contradicts the result I saw in physics class.” Explain to Isaac how he should refine his thinking to understand what is happening in that situation.

C: Release the Cart!

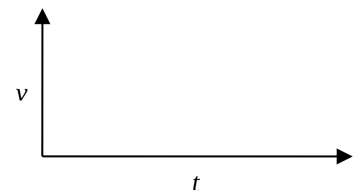
Pull the cart along the floor and then release it.

1. **Observe and Represent.** Complete the velocity graph and motion diagram for your cart. Label two events on each: (1) you release the cart, and (2) the cart stops.

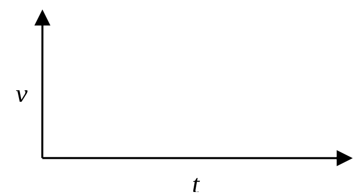




2. **Reason and Represent.** Imagine a new model: we change the cart and floor to reduce friction a bit. Explain how the motion of the cart after it is released would be different from the previous example. Sketch a velocity graph for this imaginary situation and explain how it appears different from the previous velocity graph.



3. **Predict and Represent.** Now imagine very special model: we carefully remove **all** sources of friction. After we release the cart, what would we observe in this very special situation? Sketch a velocity graph. In this situation what horizontal forces are acting on the cart?



4. **Observe.** (*as a class*) Describe the motion of the hover puck after it is released and is not pushed.

5. **Test.** (*as a class*) The hover puck is given a gentle push. Describe the motion of the hover puck *after* it is released.

D: The State of Things

In physics we use the term *state* to describe a category of motion or force. We have explored three seemingly different states of motion so far in grade 11 physics: (1) rest, (2) constant velocity, and (3) acceleration. We have just explored two seemingly different states of forces: (1) a single constant force, and (2) no forces at all. In science we look for patterns and sometimes these patterns reveal connections between things we thought were totally unrelated.

1. **Reason.** Use today’s observations to describe the state of force that corresponds to each state of motion listed below. This will start our catalogue of force-motion relationships.

State of Motion	State of Force
Constant velocity	
Acceleration	
Rest	

2. **Reason.** Do you see any similarities between states that appear to be unrelated?

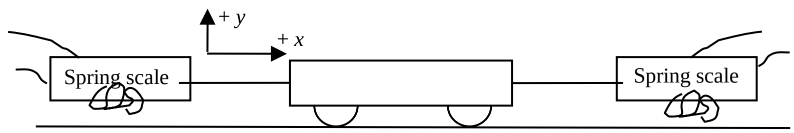
SPH3U: The Force-Motion Catalogue

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

Let's continue to explore the connection between different states of force and motion. You will need: a dynamics cart and two identical spring scales (5 or 10 N). Throughout this activity we make an important assumption: the forces of friction are very small compared to the other forces involved, so we will consider **the size of the force of friction to equal zero.**

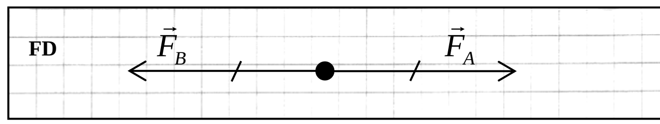
A: Two Forces

Calibrate your spring scales. Exert two equal-sized forces on the cart, but in opposite directions.



1. **Observe.** Describe the motion of the cart. Record the size of the forces.

2. **Interpret.** The force diagram (FD) to the right shows a model for the two tension forces you exerted on the cart. What do the "tick marks" and the lengths of these vectors tell us about the two forces?



The *net force* (F_{net}) is the combined effect of all the forces acting on an object or system. Since there may be forces in more than one direction (horizontal and vertical) we will often describe the forces and the net force in a particular direction ($F_{net\,x}$ or $F_{net\,y}$).

3. **Reason.** Without doing any math, what do you think the net force experienced by the cart in the *x*-direction is equal to?

To calculate the net force we will write a *component equation* using a sign convention to show directions. Forces acting in the positive direction are labelled positive and forces acting in the negative direction are labelled negative. **The values of the force symbols are all positive**. For example, if there is a single 10 N force $\vec{F}_A$ in the negative-*x* direction, we will write: $F_{net\,x} = -F_A$, where $F_A = 10$ N.

4. **Explain.** Below is the expression for the net force in the *x*-direction experienced by the cart. What do the + and – in this equation tell us about the two forces?

$$F_{net\,x} = +F_A - F_B$$

5. **Calculate.** You measured the size of the two forces acting on the cart. Substitute those values into the net force expression and find the result.

In the future, if the first symbol in the expression for the net force is positive, we won't write the positive sign. If the net force equals zero we say that the forces acting on the object are *balanced*. In part A, the forces acting on the object in the *x*-direction are balanced.

6. **Summarize.** What is the state of motion of an object that experiences balanced forces?

B: On the Move

What will happen to a cart that is already moving if it experiences balanced forces? Refer to the cart your teacher has set up at the front of the room.

1. **Represent.** Draw a FD for the cart your teacher has set up. Label the two forces. Note that the strings attached to the weights are pulling on the cart horizontally. $F_A = 5$ N and $F_B = 5$ N.

2. **Calculate.** Write an expression for the net force in the *x*-direction and calculate the result.

3. **Predict.** Your teacher will start the cart moving and then let go. Once released, the only horizontal forces acting on the cart will be the two tension forces. Think back to the conclusions we reached last class: even though the chart doesn't cover this situation, is there one state that seems "close" to this? Predict the state of motion of the cart after it is let go.

4. **Test.** (*as a class)* Describe your observations. Do they confirm your prediction? Explain.

C: Net Force is Not Zero

Now we make a small change to the cart set up at the front: we increase the size of one of the forces. $F_A = 6$ N.

1. **Represent.** Draw a FD and label the two forces. How should you draw the length of the two force vectors?

FD

2. **Calculate.** Write an expression for the net force and calculate the result.

The net force (F_{net}) is our only force quantity that can have a negative value. We interpret this to mean the net force points in the negative direction. If the net force is not equal to zero, we say that the forces acting on the object are *unbalanced*.

3. **Predict.** Again, look back to the chart from last class. Is there a state that is "close" to this one? Use this to predict the state of motion for this situation, after the cart is released.

4. **Test.** (*as a class)* Describe your observations. Do they confirm your prediction? Explain.

If a system accelerates, draw a separate wiggly acceleration vector ($\vec{a}$) alongside the force diagram.

5. **Speculate.** According to your calculation for the net force, what single force could replace the two forces in this situation? Draw a FD for this situation.

FD

6. **Test.** (*as a class)* The cart now experiences a single force equal to the net force from before. How does the acceleration of the cart compare with your previous observations?

The net force gives us the combined effect of all the forces acting on an object. The object behaves just as if a single force was acting on it that had the same magnitude and direction as the net force. Judging from only the motion of the object, we cannot tell the difference. We will call this idea the *net force principle*.

D: Three Forces!

It is now time to return to your dynamics cart. Your challenge is to create a situation where three forces act in the *x*-direction and are balanced. Get a third spring scale and try this now.

1. **Reason and Represent.** Decide how you will attach the spring scales and draw a FD. When we have multiple forces in one direction, draw the vectors *tip to tail* (in one row, not overlapping). Label the forces.

FD

2. **Calculate.** Write an expression for the net force and use your values to calculate the result.

3. **Reason.** Even if you couldn't see the readings on the spring scales, why do you believe you successfully balanced the three forces acting on the cart?

E: The Forces-Motion Catalogue

Complete the chart below showing the correspondence between all the different states of force and motion we have explored.

State of Force	**Net Force** (circle one)	**State of Motion**
No forces at all	zero / non-zero	1)
		2)
Balanced forces (two or more)	zero / non-zero	1)
		2)
One single, unbalanced force	zero / non-zero	
Unbalanced forces (two or more)	zero / non-zero	

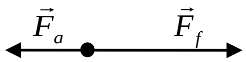
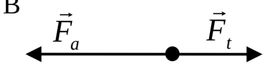
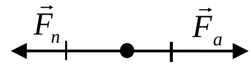
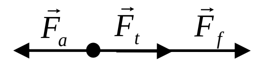
1. **Reason.** People get very excited when things that seem different are actually very similar. We have four different states of force in our chart. Can we reduce the number of states? If so, how should we label the new states of force?

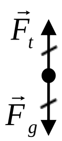
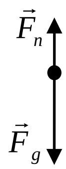
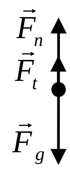
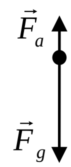
2. **Reason.** According to the chart, can we use information about forces or the state of force to decide if an object is at rest or if it is moving with a constant velocity?

Newton's First Law

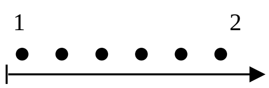
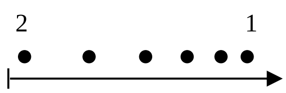
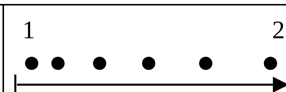
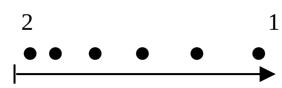
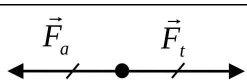
SPH3U: The Net Force Homework Name:

1. For each force diagram, decide on the state of force. Add a wiggly acceleration vector $\vec{a}$ to the force diagram, if appropriate. Write the expression for the net force in the *x- or y*-direction. Use the directions right or up as positive. What state of motion will be the result: acceleration or rest/constant velocity? Look at the sample answers for hints on what to do if you're stuck.

FD	A 	B 	C 	D 
State of Forces		unbalanced		
$F_{net\ x}$	$= F_f - F_a$			
State of motion				acceleration

FD	E 	F 	G 	H 
State of Forces	balanced			
$F_{net\ y}$		$= F_n - F_g$		
State of motion				acceleration

2. Two forces act in opposite directions on an object, F_t to the right and F_a to the left. Describe the state of motion. Compare the size of the two forces. Draw a force diagram. Include a wiggly acceleration vector when appropriate.

Motion Diagram				
State of Motion				
Compare		$F_t < F_a$		
Force Diagram				

3. You pull a wagon horizontally along the rough ground. The wagon is speeding up. Complete the chart below. Use your understanding of the states of motion and force in each direction to help you draw the force diagram.

Interaction Diagram	Vertical Direction	Horizontal Direction	Force Diagram
	State of motion: State of forces:	State of motion: State of forces:	

SPH3U: The Change of Force Principle

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

We have made a great discovery with Newton's First Law (our catalogue of force-motion relationships). Now we need to figure out what happens when forces change.

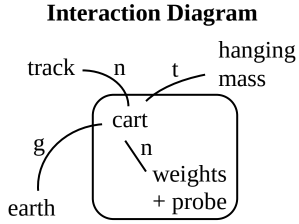
A: Systems and Interactions

Your teacher has a cart set up on a track with a motion detector and a force sensor. We will create a model for the system of the cart including the extra weights and probe. Our experiment has three events: (1) the cart is released from rest with the hanging mass pulling on it, (2) the mass hits the ground, and (3) the cart reaches the end of the track.

1. **Reason** (*as a class*)**.** Observe the cart moving along the track without the hanging mass pulling. What assumptions should we include in our model?

Objects outside the system are in the *environment*. Force diagrams only show *external forces*, which are forces from interactions between system objects and the objects in the environment. FDs do not show *internal* forces, forces from interactions between two system objects.

2. **Represent.** We will begin by focusing on the system between events 1 and 2. Complete the chart below. Use the interaction diagram to determine the number of force vectors to draw. Use your understanding of the state of motion and force in each direction to determine the size of the force vectors.

Interaction Diagram	**Vertical Direction**	**Horizontal Direction**	**Force Diagram**
	State of motion: State of force:	State of motion: State of force:	

3. **Record.** Draw your FD on your whiteboard to share with the class.

B: Change of State

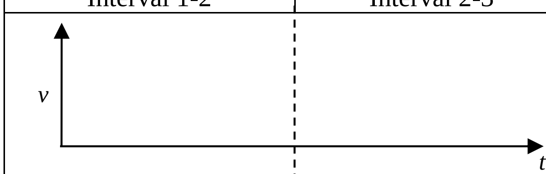
Let's return to our experiment. We are interested in exploring what happens to the state of motion when forces suddenly change.

1. **Observe and Interpret.** (*as a class)* Observe the results from the computer. Complete the velocity and tension force graphs. Label the events. Complete the rest of the chart.

2. **Interpret.** During this experiment the state of motion changes and the state of the forces change. What do you notice about the timing of these two changes?

When the net force experienced by a system changes, the acceleration changes at the same time. There is no delay between one and the other – the changes are simultaneous. We will call this idea the *change of force principle*. This is an important part of Newton's First Law.

3. **Reason.** Isaac says, "When the counterweight stops pulling on the cart, I don't understand **why** the cart moves with a constant velocity. I think we should draw a forwards force on the FD for interval 2-3." Do you agree or disagree with Isaac? Explain.

Interval 1-2	Interval 2-3
	
State of Motion:	State of Motion:
	
State of Forces:	State of Forces:
FD	FD

C: Throw in the Towel

Now we will repeat this experiment with just one change – a piece of paper towel is taped underneath the cart such that it rubs on the track as the cart moves.

1. **Predict**. There are three common hypotheses to explain what happens in this situation.

   Hypothesis A: After the force of tension stops the cart moves for a while, and later friction starts to slow it down.

   Hypothesis B: When the force of tension stops, the cart *immediately* stops due to the force of friction.

   Hypothesis C: When the force of tension stops, the state of motion changes right away to a new acceleration.

   Use each hypothesis to predict a velocity graph for the cart. Draw each prediction in the chart.

2. **Test and Evaluate.** (*as a class*) Use the computer results to test the predictions. Evaluate which hypothesis is supported and which is refuted.

3. **Represent.** Complete the chart. Draw a FD for the cart during each interval. Write an expression for the net force in the *x*- and *y*-directions.

Interval 1-2	Interval 2-3
Prediction A v	t
Prediction B v	t
Prediction C v	t
F_t	t
FD	FD
$F_{net\ x} =$	$F_{net\ x} =$
$F_{net\ y} =$	$F_{net\ y} =$

All ordinary matter has a property called *inertia*. When forces are unbalanced, it takes **time** for the velocity of an object to change. In some cases the time interval for the change can be very small, but it is **never** zero. We will call this idea the *inertia principle*. The amount of time is related to the size of the net force and the amount of inertia (the mass). This is a first hint at another law of physics!

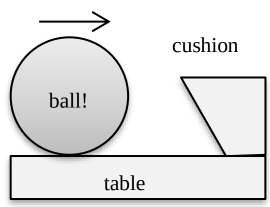
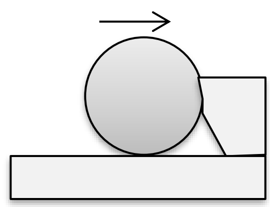
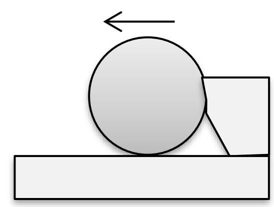
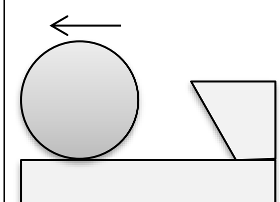
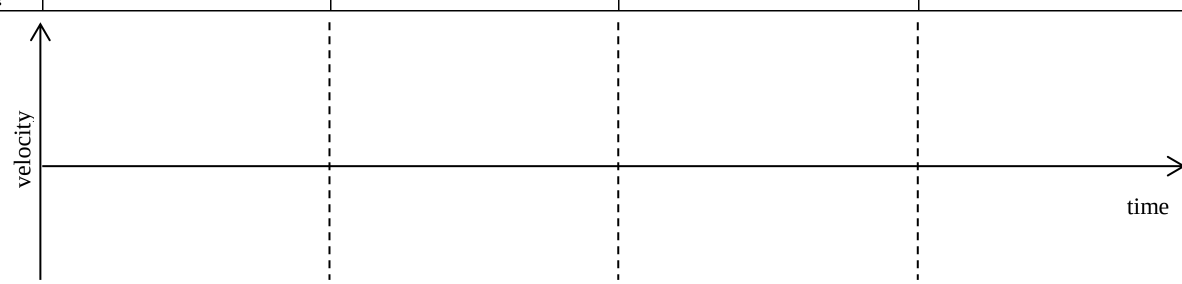
4. **Reason.** Albert says, "I'm pretty sure that when I push a heavy box along the floor and let go, its state of motion changes suddenly from constant velocity to rest." Do you agree with Albert? Explain why he might have this understanding.

A: The Billiards Game

In the game of billiards (sometimes known as "pool"), a ball bounces off the cushion at the side of a table. Friction between the ball and the table surface is very small compared with other forces, so make an assumption in your model. We choose five events to help us explore what happens:

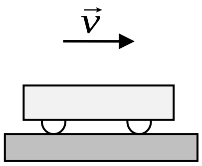
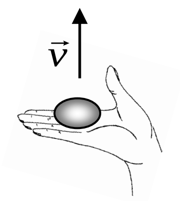
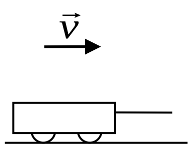
(1) The ball is travelling towards the cushion.
(2) The ball makes contact with the cushion.
(3) The cushion is squished and the ball stops.
(4) The ball leaves contact with the cushion.
(5) The ball is travelling away from the cushion.

1. **Reason and Represent.** For each interval of time between the pairs of events:
   (a) Draw an interaction diagram and a force diagram. The possible interacting objects are ball, Earth, table and cushion. Label the normal forces $F_{n\ c\text{-}b}$ (normal force of cushion on ball) and $F_{n\ t\text{-}b}$ (normal force of table on ball)
   (b) Describe the state of forces, the state of motion, and what is happening to the speed.
   (c) Sketch a velocity time graph and label the events (the graph is divided up according to the time intervals).

Interval	1-2	2-3	3-4	4-5
Description	Ball rolls towards cushion	Cushion becomes squished (compressed)	Cushion expands	Ball rolls away from cushion
Sketch				
Interaction Diagram				
Force Diagram				
State of Forces				
State of Motion				
Speeding Up or Slowing Down?				
Velocity Graph				

SPH3U: Force of Gravity Homework

1. **Represent.** Complete the chart for each situation described.

	Description	Sketch	Interaction Diagram	Force Diagram	Net Force
1	A cart glides along a table with no friction. System = cart				$F_{net\ x}$ = $F_{net\ y}$ =
2	A tasty chocolate in your hand is moving upwards with a constant speed. System = chocolate				
3	You lower a ball using a string. It *slows down*. System = ball				
4	You pull along the horizontal handle of a wagon. It travels along the rough ground and speeds up. System = wagon				

2. **Calculate.** The chocolate in situation #2 has a mass of 20 g. We want to find the size of the upwards force you exert on the chocolate. Albert is having difficulty with this. Explain to him what happens in each step of the work presented to the right.

	$F_{net\ y} = F_a - F_g = 0$
	$\therefore F_a = F_g$
	$\therefore F_a = mg$
	= (0.020 kg)(9.8 N/kg)
	= 1.96 N
	The upwards force has a size of 1.96 N

3. **Calculate.** The dumbbell in situation #3 has a mass of 10 kg and you pull upwards with a force of 15 N. What is the size of the normal force?

4. **Calculate.** The wagon in situation #4 experiences a net force of 30 N and a force of friction of 10 N. What is the size of the pulling force?

Answers: (3) 88 N, (4) 40 N

SPH3U: The Force of Gravity!

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

How does an object's mass affect the size of the force of gravity it experiences? Let's find out. You will need: one 10-N spring scale, a hanging mass, a variety of masses, and some gravity.

A force that is noticeable only when two objects are in contact, is a *contact force*. Any force that has a noticeable effect even when the objects are separated is called a *non-contact force*.

1. **Reason.** Is gravity a contact force or a non-contact force? How can we tell?

2. **Represent.** Draw an ID and a FD for the hanging mass. Explain why we can use the scale reading (an upwards force of tension) to determine the size of the force of gravity.

ID	**FD**

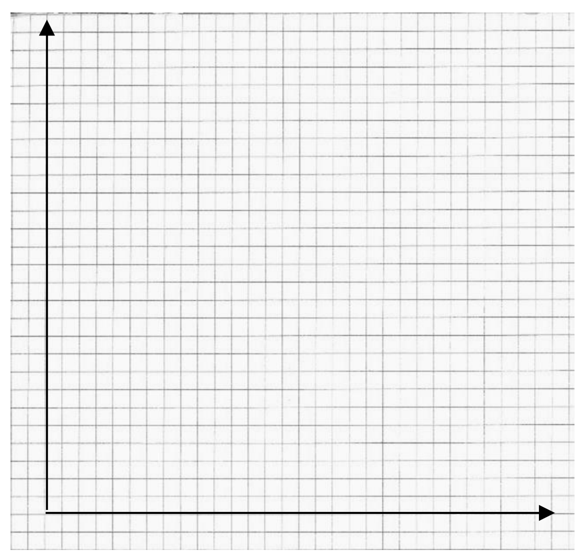
3. **Design.** We want to find out how the magnitude of the force of gravity depends on the mass of the object. Describe how you will conduct a simple experiment to collect data and determine this.

4. **Observe.** Record your data in the chart.

5. **Analyze.** Decide which variable is the dependent one. Plot your data on the graph. Use the shape of the graph to describe how the force depends on the mass.

6. **Calculate.** Determine the slope of your graph, including units. Show your work on the graph.

Mass, *m* (kg)	Force of Gravity, F_g (N)
0	



The slope of your graph gives a very important quantity, the *local gravitational field strength* $\vec{g}$. It tells us how much force the earth's gravity exerts on each kilogram of matter in an object at this location. The exact value depends on many factors including geographic location, altitude, and planet. The accepted value for your location is: _______ N/kg [down].

7. **Analyze.** Write an equation for your line of best fit. Be sure to write "$y = mx+b$" using physics symbols.

8. **Apply.** Use your new equation to determine the size of the force of gravity acting on a 1.5×10^3 kg car.

SPH3U: Normal Forces Homework Name:

You grab your physics textbook off a shelf and lower it down on to your desk in preparation for doing your homework. (What a good student you are!) As the book moves, it lies flat on the palm of your hand. Let's take a look at the physics of this **daily** routine. There are four important events that take place: (1) The book begins to speed up as it starts moving downwards, (2) the book reaches a constant velocity, (3) the book begins to slow down as it nears the desk, and (4) the book comes to rest at the bottom.

ID

1. **Represent.** Draw an interaction diagram for the system of the book during this sequence of events.

2. **Represent.** Complete the chart below for each of the three intervals in the book's downwards motion.

3. **Explain.** Which force changes during this sequence of events? How does that affect the book's motion?

Interval	1-2	2-3	3-4
Motion Diagram	$+y$	$+y$	$+y$
Force Diagram			
Net Force	=	=	=

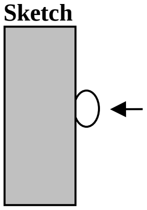
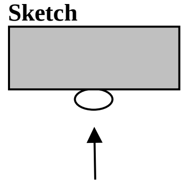
4. **Calculate.** The mass of the book is 1.3 kg. What is the size of the force exerted by your hand between events 2 and 3?

5. **Test and Describe.** Try this. Find a heavy book and place it on the palm of your hand just like in the picture. Lower the book just as we have described above. Try to connect how it feels in your hand when you do this with your understanding of the forces. Describe what you notice.

5. **Reason.** Your friend places the same book on a table. She then leans on top of it, pushing down with 7 N of force. Draw a FD for book with and without the downwards push. Compare the size of all the forces in the two diagrams.

FD – no push	FD –push

6. **Represent.** You throw a very bouncy ball which hits a wall and then the ceiling. Draw an ID and a FD for the ball while it is (a) in contact with the wall and (b) in contact with the ceiling. Hint: the direction of the acceleration vector is tricky – just make a guess based on the FD.

Sketch	**ID**	**FD**	**Sketch**	**ID**	**FD**
					

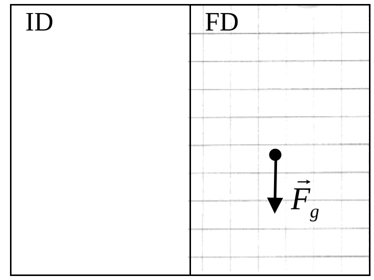
SPH3U: The Normal Force

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: A Mysterious Force

Your friend places her backpack on a table. The backpack is the system.

1. **Reason.** Your friend draws a FD for the system and says, "I'm really not sure that there should be an upwards force." Convince your friend. Cite direct evidence about the system that you can readily observe.



2. **Reason.** Complete her original FD and draw an ID. The backpack has a mass of 5.8 kg (all those textbooks). What is the size of the upwards force?

When two objects press against one another, they interact and exert *normal forces* on one another. A normal force (F_n) is a contact force that is always perpendicular to the surfaces at the point of contact. This force usually prevents objects from deforming by much, from breaking or from merging together. When a person is in contact with another object, we call this special normal force an *applied force*. Note that an applied force can also be a combination of a normal force and a friction force (which we will study later).

B: Evidence for the Normal Force

For these activities you need two metre sticks, a spring scale and a 500 g mass. Make a bridge using the metre stick between two tables. Gently press downwards with your finger in the middle of the metre stick.

1. **Observe.** Describe what you observe happening to the "rigid" metre stick. Why did the shape change?

2. **Reason.** Describe the evidence you feel for the existence of an upwards force acting on your finger.

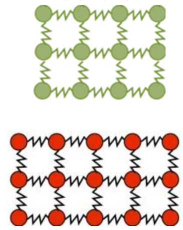
3. **Observe.** Place the 500 g mass on the metre stick. Describe what happens. What is the size of the upwards normal force?

4. **Observe.** Remove the mass. Place the second metre stick directly on top of the first (the "table" is now twice as thick). Place the 500 g mass on top of the two sticks. What is different about the effect of the mass on our thicker "table"? How has the upwards normal force changed? Explain.

*** Check with your teacher before proceeding. ***

5. **Reason.** Imagine many, many metre sticks stacked up (a very thick table). What would happen to the metre sticks if we place the 500 g mass on top of them? How has the size of the upwards normal force changed compared to the single metre stick situation? Explain.

6. **Explain.** *(as a class)* How does the normal force work on a microscopic level?

A Physical Model for the Normal Force	Particles Before Contact	Particles After Contact
		

C: Measuring the Normal Force

You need a 0.5-kg mass and a 5 N spring scale. Place the mass on the table.

1. **Reason.** What is the size of the upwards normal force on the mass? Explain.

2. **Analyze and Predict.** In a moment you will pull upwards on the mass with a 3 N force.
(a) Draw an ID and a FD for this situation.
(b) What is the state of the forces? Write an expression for $F_{net\ y}$.

(c) Predict the size of the normal force in this situation.

ID	**FD**

3. **Test.** Attach a spring scale to the mass and exert a 3 N force upwards. Try this with the mass on your hand. How did the sensation in your hand change?

4. **Test**. Place the mass on the force pad and exert the 3 N force upwards. Determine the size of the normal force. Does this result agree with your prediction? Explain.

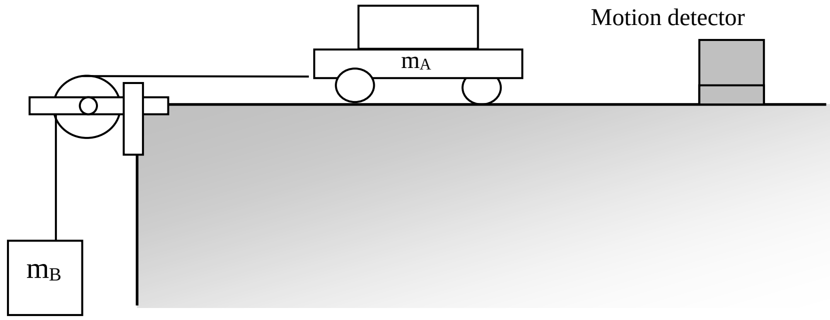
The magnitude of the normal force depends on how hard the objects are pressing against one another. Other forces and motion may affect the size of a normal force. As a result, we always have to find the size of the normal force by analyzing what's happening to the system.

SPH3U: Force, Mass and Acceleration

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

What factors affect the acceleration of an object? We have already hinted that force and mass are key. Today's investigation will help you understand how these quantities affect the acceleration.

Your group will use the carts and masses set up in the classroom. A motion detector will help track the velocity of the cart. Complete **all** the questions below before beginning the experiment and show this page to your teacher.



A: The Atwood Machine

1. **Reason.** Why does each mass, m_A and m_B, move when released. What forces cause the acceleration of each mass?

2. **Reason.** When the mass m_A is released how much mass is moving in total?

3. **Reason.** We can think of the two masses as a single system. What single force is the ultimate cause of the acceleration of the entire system (m_A and m_B together)? This is the force we will vary in our experiment.

4. **Reason.** To conduct a scientific investigation one must always change only one quantity and measure the results while ensuring that everything else remains unchanged. Suppose you want to increase the force moving the system while keeping everything else the same. You add 50 g to m_B. What else **must** you do?

B: Investigating the Effects of Force

In the first experiment you will vary the force while keeping all other properties constant, to determine the effect of the net force on the acceleration. The computer will produce a velocity-time graph for you to analyze.

1. **Design an Experiment.** Describe how you will conduct your experiment. Show your teacher when you are ready.

2. **Observe.** What is the total mass of your system ($m_A + m_B$)? Remember, you must keep this constant!

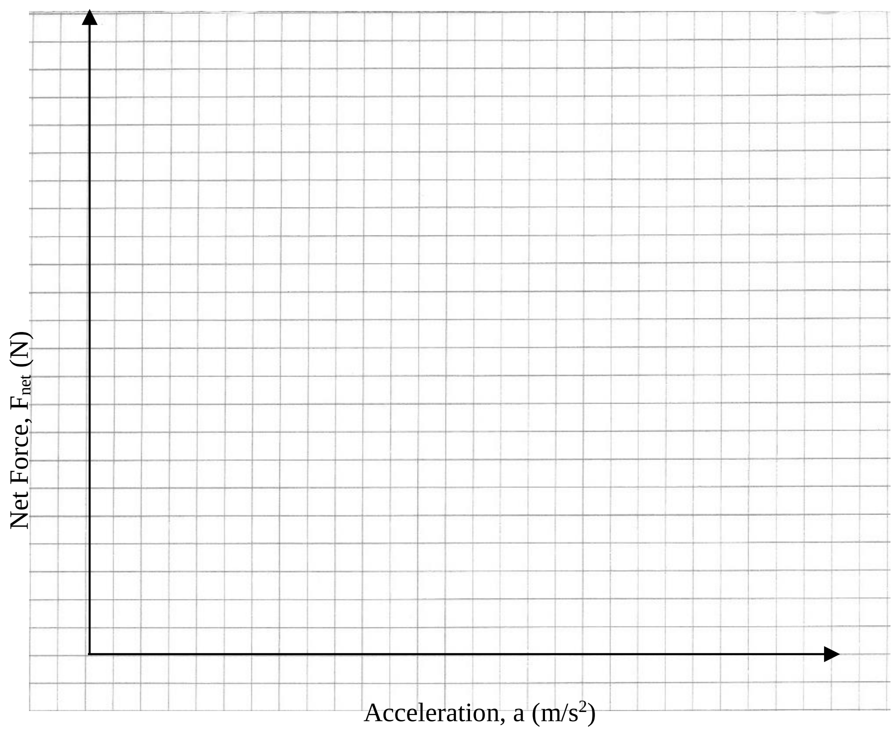
3. **Observe.** (*as a class*) Conduct the experiment and record your results in the chart below. Make fairly large changes in the masses (about 200 g). If m_B becomes too large the motion detector may have difficulty making measurements.

m_A (kg)	m_B (kg)	System Mass (kg)	Net Force (N)	Acceleration (m/s^2)

4. **Represent.** Construct a graph of your results with the **net force on the vertical axis**. We are choosing the axes this way to help with the interpretation of the slope at a later step. Draw a line of best fit.

5. **Interpret.** Use the pattern in your graph to help explain how acceleration depends on force.

6. **Calculate.** Determine the slope of the line of best fit. Show your work.



7. **Interpret.** Is the value of the slope close to any other quantities which describe our system? What do you think the slope physically represents about the object?

8. **Represent.** Write an equation for the line on your graph. Remember to use physics symbols!

9. **Reason.** If we double the force acting on the system (and keep the mass constant), what will happen to the acceleration?

10. **Reason.** If we reduce the force to one third (and keep the mass constant), what will happen to the acceleration?

C: The Effect of Mass on Acceleration

This is a quick investigation what will help us to determine how changing the mass of the system will affect the acceleration, when the net force remains constant.

1. **Design an Experiment.** We want to double the mass of the system and keep the net force constant. Choose your original values and changed values for m_A and m_B that will accomplish this. Keep in mind the actual mass of the cart as you do this.

Original	**Changed**
m_A :	m_A :
m_B :	m_B :
System mass:	System mass:
Net force:	Net force:

2. **Observe.** Use the Atwood machine and motion detector to conduct your investigation. Record your results below.

Original	**Changed**
System mass:	System mass:
Acceleration:	Acceleration :

3. **Find a Pattern.** Roughly speaking what happened to the value of the acceleration when you doubled the mass?

4. **Reason.** What do you think the acceleration would be if you were able to reduce the original system mass by half? Explain.

D: Conclusions

1. **Evaluate.** Earlier you created an equation that shows the relationship between the net force (F_{net}), the mass (m) and the acceleration (a) of a system. Does this equation include the two key results from your two experiments: acceleration depends on mass and acceleration depends on the net force? Use phrases like "if you double the ______ and _______ remains constant, the _________ doubles" to explain.

2. **Summarize.** (*as a class*)

Newton's Second Law

Newton's Second Law is the rule for our universe that describes the relation between cause (forces) and effects (acceleration).

3. **Apply.** We can use Newton's 2^{nd} Law to explain what 1 N of force is and find the hidden meaning of the unit newton (N).
   (a) Use the equation for the 2^{nd} law to find the net force experienced by a 1.0 kg mass that accelerates at 1.0 m/s^2.

   (b) Your result shows the fundamental units that the newton (N) is equivalent to. As a result, the symbol N is short form for what basic units?

SPH3U: Force, Mass and Acceleration Homework Name:

Newton's Second Law ($F_{net} = ma$) is the rule for our universe that describes the relation between cause (forces) and effects (acceleration).

A: The Units of Force

1. **Represent and Explain.** A 3 kg rock is falling to the ground.
   (a) Draw an ID and FD.
   (b) Determine the size for the force of gravity acting on the rock.

ID	FD

   (c) Use Newton's second law to find the acceleration of the rock while it is falling. Explain why the units of the calculation work out to give an acceleration. (Hint: You can replace the symbol N with what other units?)

B: Find the Missing Force

1. You pull your friend on a wagon using a horizontal, forwards force. There is a small amount of friction. The wagon is gradually speeding up.
   (a) **Represent.** Draw an ID and a FD for the system of wagon + friend.

ID	FD

   (b) **Reason.** Which horizontal force is larger? Explain.

   (c) **Represent.** Complete the expressions for the Newton's second law in the *x*- and *y*-directions. Use the symbols for the forces and a sign convention. If the acceleration in a direction is zero, substitute that in your expression.

$$F_{net\,x} = ma_x \qquad\qquad F_{net\,y} = ma_y$$
$$= \qquad\qquad\qquad =$$

   (d) **Reason.** The mass of your friend is 57 kg. The mass of the wagon is 12 kg. What is the mass of the system? What mass value will you substitute for *m* in your equation? Explain.

   (e) **Reason**. Your friend speeds up at a rate of 1.1 m/s^2. You pull with a force of 97 N. You are interested in finding the size of the force of friction. Which component equation for Newton's 2nd law will help you find F_f?

   (f) **Solve.** What is the size of the force of friction?

Answers: (1) 29.4 N, 9.8 m/s^2 downwards, (2) 21.1 N

SPH3U: Modelling Problems Using the 2nd Law

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Newton's 2nd Law, $F_{net} = ma$, is the law of cause and effect: it relates the causes of motion (forces) with its effects (acceleration). As a result, any problem that involves both force and motion will likely use the 2nd law. To understand the force side of the equation we use force diagrams and calculate the net force. To understand the acceleration side we use motion diagrams and the BIG 5 equations.

A: The Cart and Hanging Mass

Today our goal is to create a model that will allow us to predict the velocity of a cart pulled by a hanging mass. Similar to the previous investigation, our **system is the cart plus hanging mass**.

1. **Reason.** All models depend on assumptions and are valid for certain time intervals. Describe your assumptions in part C and describe the events that start and end your time interval in part A.
2. **Measure.** You will need to know some information about your system. Examine the equipment and record the information in part A below. Your teacher will give you a value for the force of friction.
3. **Predict.** The purpose of this model is to predict the velocity of the cart 0.75 s after it is released. Complete the steps of the solution process below to determine your prediction.

A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns with symbols, conversions, describe events

B: Physics Representation

Interaction diagram (system = cart + hanging mass), force diagram

The force of gravity on the hanging mass causes the system to accelerate. Show this as a horizontal force F_{hm} on your FD.

C: Word Representation

Describe motion (no numbers), explain why, assumptions, estimation (no calculations)

Did you explain *why* it speeds up?
What are we assuming about this model?

D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction.

What is the mass of the system?

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

4. **Test.** You have made a prediction using your model. Test your prediction using the motion detector. Does the measurement agree with your prediction?

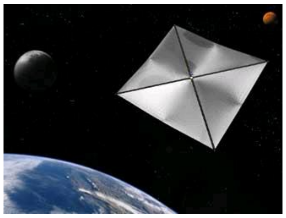
5. **Evaluate.** Scientists test models, evaluate their reliability, and search for ways to improve their models. You probably found that your prediction was close, but still noticeably different from the measured result. What accounts for this difference? Are there other sources of friction? If you wanted to build an improved model, what would you try to measure to add more information?

B: Sample Problems

Use a forces solution sheet for your solutions. Use the check list below to help improve the quality of your solutions.

- ☐ I described the events carefully. Sometimes the descriptions are very simple. (e.g. Event 2 = 1.5 s later)
- ☐ I used the forces unit rubric to check the quality of my IDs and FDs.
- ☐ I compared the size of forces to explain why the system is accelerating.
- ☐ I carefully described the physics of each step with clear, complete phrases. (I didn't write, for example, "find a")

1. The Elevator. An elevator and its load have a combined mass of 1600 kg. It is initially moving downwards at 3.2 m/s. When the elevator passes the second floor, a motor attached to the cable supporting the elevator causes it to slow down through a distance of 8.7 m, allowing the people to get out on the first floor. What is the size of the force of tension in the cable?



2. Sunjamming. A "sun yacht" is a spacecraft with a large sail that is pushed by the force of sunlight (F_L). Although such a push is tiny in everyday circumstances, it can be large enough to send the spacecraft outward from the Sun on a cost-free but slow trip. Your spacecraft has a mass of 900 kg and receives a steady push of 20 N from the sun. It starts its trip from rest. How far will it travel in 1.0 days and how fast will it then be moving?

3. Two People Pull. Two people are having a tug-of-war and pull on a 25 kg sled that starts at rest on frictionless ice. The forces suddenly change as one person tugs harder with a force of 92 N compared with the other person's force of 90 N. How quickly is the sled moving after 1.5 s?

4. Take Off. A Navy jet with a mass of 2.3×10^4 kg requires an airspeed of 85 m/s for liftoff. The engine develops a maximum force of 1.07×10^5 N, but that is insufficient for reaching takeoff speed in the 90 m runway available on an aircraft carrier. What minimum force is needed from the catapult that is used to help launch the jet?

Answers: (1) 16 600 N, (2) 8.29×10^7 m, 1.92×10^3 m/s, (3) 0.12 m/s, (4) 8.16×10^5 N

Adapted from Cummings, K., et al, *Understanding Physics*. Wiley, 2004

SPH3U: Exploring Freefall

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A fascinating example of force and motion is that of falling objects. How does an object move when it is falling? Let's find out!

A: Drop the Ball!

There is a motion detector attached to the ceiling of the classroom. A student will hold a large ball of playdoh underneath the detector and release it (no downwards push). We will focus on what happens as it drops and lands on the ground.

1. **Observe.** (*as a class*) Sketch the results from the computer for the velocity graph of the ball. The graph might show a repeating pattern.

2. **Explain.** (*as a group*) Using a velocity graph, how can we decide when the acceleration is constant?

3. **Interpret.** We will choose to mark an event when the acceleration of the ball changes or its velocity is zero. Label the three events: (1) The ball is released, (2) the ball makes contact with the ground, and (3) the velocity of the ball is zero.

4. **Interpret.** For each interval of time between your events, decide whether the ball is speeding up (SU) or slowing down (SD). Label this on the graph.

5. **Represent.** There are two intervals of time between the three events we have chosen. For each interval of time, describe the states of motion and force. Draw an interaction diagram, and draw a force diagram.

Interval	1-2	2-3
State of Motion		
State of Forces		
Interaction Diagram		
Force Diagram		

In our model, *freefall* occurs whenever an object moves vertically under the influence of gravity alone. We assume that there are no forces other the force of gravity.

6. **Reason.** During which interval(s) of time did freefall occur? Explain here and label these regions above your chart and above your graph.

7. **Predict.** Use Newton's 2nd law to predict the size and direction of the ball's acceleration during freefall. (Hint: we don't know the mass of the ball, so just use the symbol *m*).

In our model, the acceleration value of a freefalling object, the *freefall acceleration* a_f, has a constant value of:

8. **Evaluate.** Use the computer data from the velocity graph for the ball drop to determine the acceleration. Does this agree with your prediction? What assumption might explain why your prediction is off by a small amount?

B: Analyzing the Motion of a Tossed Ball

A student will hold a ball underneath the detector, throw it straight up and down, and catch it. The student should begin and end the throwing motion with his or her hands low down.

1. **Observe.** (*as a class*) Sketch the results from the computer for the velocity graph of the ball.

2. **Interpret.** (*as a group*) There are five (!) important events that we would like to focus on. Label these on your velocity graph.
   (1) the hand begins to push the ball upwards
   (2) the ball leaves contact with the hand
   (3) the ball reaches its highest point
   (4) the ball makes contact with the hand
   (5) the ball stops

3. **Represent.** Complete the chart below.

Interval	1-2	2-3	3-4	4-5
State of Motion				
State of Forces				
Interaction Diagram				
Force Diagram				

4. **Reason.** Isaac says, "At its highest point, the acceleration of the ball is zero. We know that because it is turning around." Do you agree or disagree? Explain.

5. **Reason.** Emmy says, "At its highest point, the ball has a velocity of zero." Marie says, "I agree and at its highest point it remains at rest for a short interval of time." Who do you agree with? Explain.

6. **Reason.** At which event does freefall begin? At which event does it end? Explain.

7. **Reason.** The BIG 5 equations are valid (they will give reliable results) as long as the acceleration is constant.
   (a) Could you use a BIG 5 equation to make a calculation for the interval between events 3 and 5?

   (b) What about for the interval between events 2 and 4?

SPH3U Homework: Exploring Freefall   Name:

A: The Rising Ball

In class, a student threw a ball upwards underneath the motion detector. For this situation, we will use the same event numbers as we did in class.

1. **Represent.** Draw an interaction diagram and a force diagram for the ball during the intervals 1-2 and 2-3. Label the interval that is freefall.

Interval 1-2		**Interval 2-3**	
ID	FD	ID	FD

2. **Predict.** Based on our motion detector measurements in class, we observe that the ball leave contact with the hand with a velocity of 3.3 m/s upwards. Use our freefall model to predict how high the ball will travel above the student's hand. (Hint: what is the speed of the ball at event 3?)

3. **Evaluate.** According to the position measurements of the motion detector, the ball traveled 61 cm above the hand. How does your height prediction compare with the data collected from the computer?

4. **Evaluate.** Is the actual acceleration larger or smaller than in our model? (Look back at the investigation) Can that explain the difference between your prediction and the measured result?

5. **Calculate.** The student moved the ball upwards during interval 1-2 by pushing upwards on the ball for a distance of about 40 cm. What is the size and direction of the acceleration of the ball while it was in contact with the hand? (Hint: we know two of the velocities for interval 1-2!)

6. **Calculate.** The student exerted an upward force on the 566 g ball during interval 1-2. Assume that the size of this force was constant. Use Newton's 2nd law to determine the size of this force.

Answers: (2) 55.6 cm, (5) 13.6 m/s^2, (6) 13.2 N

SPH3U: Testing Freefall Acceleration

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Last class we predicted that an object in freefall would accelerate downwards at a rate of 9.8 m/s^2. Our measured result from the velocity graph was different from this. We need to explore why.

A: Testing Hypotheses – Science!

When people see something strange happening, they invent *hypotheses*: different explanations for why something happens a certain way. A good hypothesis is specific and can be used to create a *prediction*: a description of what will happen in a situation according to a particular hypothesis. A prediction is only useful if it can be tested using an experiment.

1. **Hypothesize.** Create two different hypotheses that provide possible explanations why the measured acceleration result was different from the predicted value of 9.8 m/s^2. Try to be specific.

   (1)

   (2)

To test a hypothesis, you need to design a *testing* experiment. A good testing experiment will produce evidence that either supports or refutes the predictions made using different hypotheses. A poor experiment yields results that are ambiguous and don't rule out any hypotheses.

2. **Design.** Create a testing experiment that will help support or refute one of your hypotheses above. Your experiment should involve materials and techniques that you are possible in our classroom. Describe your experiment.

** call your teacher over to provide feedback for your testing experiment **

3. **Predict.** If the hypothesis is correct, describe the outcome of the experiment.

4. **Test.** Record your observations from the experiment.

5. **Evaluate.** Decide whether the experimental result supports or refutes your hypothesis.

6. **Record.** Use at most 15 words to report your results on a whiteboard. **Briefly** state the hypothesis you tested and whether it was supported or refuted. Since there are always uncertainties in experiments, we want to look for a consensus in the class.

Summary of Freefall Model

The Air Resistance Assumption: In grades 11 and 12, the size of the force of air resistance (F_{air}) is almost always much smaller than the other forces involved. As a result, we will assume that the size of air resistance is zero. We will only include air resistance in a model if the situation does not make sense without it (like a person with a parachute).

B: The Freefall Problem

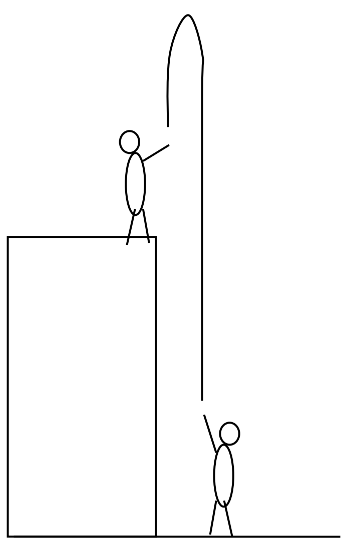
Timothy, a student no longer at our school, has climbed up on to the roof of our school. Emily is standing below and tosses a ball straight upwards to Timothy. The ball travels up past him, comes back down and he reaches out and catches it. Tim catches the ball 6.0 m above Emily's hands. The ball was travelling at 12.0 m/s upwards, the moment it left Emily's hand. We would like to know how much time this trip takes.

1. **Represent.** Complete part A below. Draw a coordinate system that shows the *y*-origin for position measurements and where upwards is positive. Only label the events that define the start and end moments of the problem.

2. **Represent.** Complete part B below. Make sure the two graphs line-up vertically. Draw a single dotted vertical line through the graphs indicating the moment when the ball is at its highest.

A: Pictorial Representation

Sketch, coordinate system, label givens & unknowns, conversions, describe events

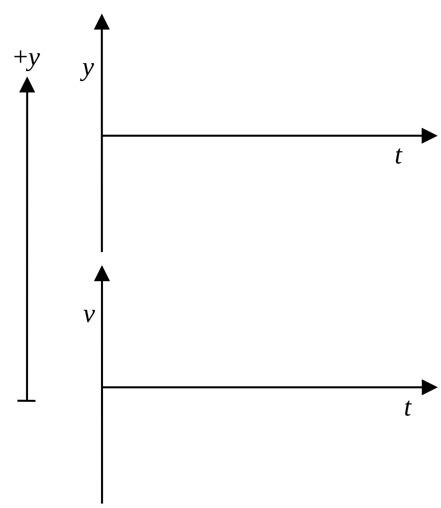


Event ①:

Event ②:

B: Physics Representation

Motion diagram, motion graphs, events



3. **Reason.** We would like to find the displacement of the ball while in freefall. Some students argue that we can't easily tell what the displacement is since we don't know how high the ball goes. Explain why it is possible and illustrate this displacement with an arrow on the sketch.

The total length of the path traveled by an object is the *distance*. The change in position, from one event to another is the *displacement*. Distance is a scalar quantity and displacement is a vector quantity. The magnitude of the displacement is the same as the distance only when then direction (the sign of the velocity) does not change.

4. **Reason.** The BIG 5 equations are valid for an entire interval of constant acceleration. Is the acceleration of the ball constant between the two events you chose? Explain.

5. **Reason.** Isaac says, "I want to use an interval of time that ends when the ball comes to a stop in Tim's hand. Then we know that $v_2 = 0$." Why is Isaac incorrect? Explain.

6. **Solve.** Choose a BIG five equation to solve for the time. (Hint: one single BIG 5 equation will solve this problem). Note that you will need the quadratic formula to do this! $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ For convenience you may leave out the units for the quadratic step.

D: Mathematical Representation

Describe steps, complete equations, algebraically isolate, substitutions with units, final statement

7. **Interpret.** Now we have an interesting result or *pair* of results! Why are there two solutions to this problem? How do we physically interpret this? Which one is the desired solution? Explain using a simple sketch.

8. **Interpret.** State your final answer to the problem.

Homework: Freefalling

1. Isaac is practicing his volleyball skills by volleying a ball straight up and down, over and over again. His teammate Marie notices that after one volley, the ball rises 3.6 m above Isaac's hands. What is the speed with which the ball left Isaac's hand? Hint: carefully choose your events and decide how the given information matches the events.

2. With a terrific crack and the bases loaded, Albert hits a baseball directly upwards. The ball returns back down 4.1 s after the hit and is easily caught by the catcher, thus ending the ninth inning and Albert's chances to win the World Series. How high did the ball go?

3. Emmy stands on a bridge and throws a rock at 7.5 m/s upwards. She throws an identical rock with the same speed downwards. In each case, she releases the rock 10.3 m above a river that passes under the bridge. Which rock makes a bigger splash? Hint: set this up as two problems, but draw your graphs on one set of axes.

Answers: (1) 8.40 m/s, (2) 20.6 m, (3) same

SPH3U: Interaction Forces

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

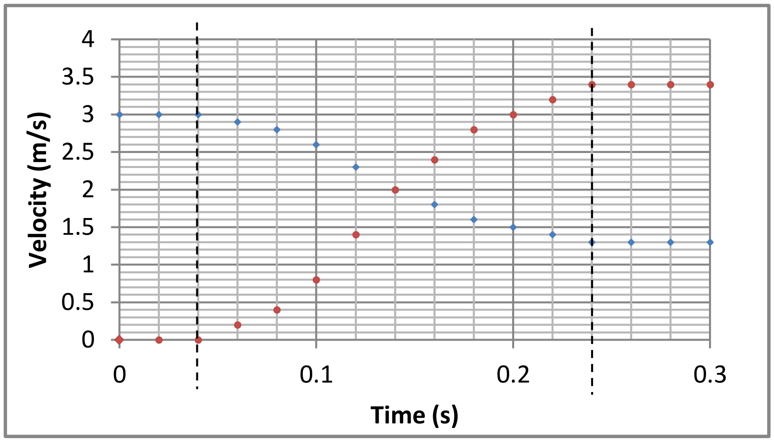
A: Truck vs. Car!

A fast moving truck collides with a Smart Car at rest. In this situation there are two possible forces: a force the truck exerts on the car, $\vec{F}_{T-C}$, and a force the car exerts on the truck, $\vec{F}_{C-T}$.

1. **Explain.** Why, according to common sense, might someone decide that $F_{T\text{-}C}$ is larger than $F_{C\text{-}T}$?

B: Analysis - Acceleration

We will model this collision with a large and small dynamics cart (500 g, 250 g). Using motion detectors, we can collect velocity data during their collision. This data is shown in the graph to the right. The positive direction is to the right.



1. **Explain.** How can we tell that the dotted vertical lines correctly represent the starting and ending moments of the collision?

2. **Interpret.** What is the duration of the collision?

3. **Calculate.** Use the velocity information to find the average acceleration (including direction) of each cart during the complete collision. Show all your work.

4. **Explain.** Which cart experienced the greater acceleration? Is this surprising? How does this agree with your visual impression of what happens?

5. **Reason.** Imagine the carts were vehicles in a collision. Based on the acceleration results, which one would you prefer to be in? Explain.

C: Analysis - Forces

It is clear from the data and your calculations that the small cart reacts more during the collision – its acceleration is the greatest. But this is not the end of the story. Acceleration is the *result* of force, and we have not yet found the forces responsible. In this collision, the forces the carts exert upon one another are much larger than the force of friction. Therefore it is reasonable to ignore friction and assume that there is only one important horizontal force acting on each cart.

1. **Represent.** Draw one single ID for the two carts and circle each cart showing that you are choosing <u>two</u> systems.

ID

2. **Represent.** Draw an FD for each cart. Label the forces $\vec{F}_{L-S}$, meaning the force of the large cart on the small cart, and $\vec{F}_{S-L}$, meaning the force of the small cart on the large cart.

3. **Calculate.** Use Newton's 2^{nd} law to find the magnitude of the forces using your acceleration results. Watch the signs!

System = large cart	System = small cart
FD	FD
2^{nd} Law	2^{nd} Law

4. **Explain.** How does the magnitude of $\vec{F}_{L-S}$ compare with $\vec{F}_{S-L}$? Is this result surprising? Why?

5. **Interpret.** The force results seem like a contradiction of our common sense. We must re-interpret what our common sense is actually telling us. When we observe a collision between a car and truck, are we observing forces or accelerations? Explain.

6. **Explain.** Another strange aspect of this result is that forces of equal size produce such different acceleration results. How is this possible?

D: Test this Idea

1. **Challenge.** We have explored just one situation and found that the sizes of the two interaction forces are the same. Maybe other situations are different? Maybe they are the same? Propose other situations involving the carts (you can change the masses, velocities, etc.) where you think the two interaction forces might be the same or might be different.

SPH3U: Newton's Third Law

Recorder: ________________
Manager: ________________
Speaker: ________________
0 1 2 3 4 5

The case we have just studied of colliding carts points to a very general law about forces. The idea that the interaction forces between two objects (the carts) are equal in size holds true for all physical objects. This idea is known as *Newton's 3rd Law*.

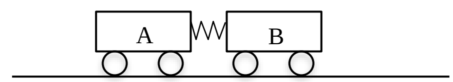
When objects interact, a pair of forces is always produced – they are two parts of one interaction. We call these two forces a *third law force pair*. The two forces that are members of the same third law pair share some important characteristics.

- the same magnitude
- opposite directions
- the same type (gravitational, normal, tension, etc.)
- start and stop acting at the same time
- act on different objects

We can use *3rd law notation* for forces to help show these relationships. $\vec{F}_{n\ c-t}$ means the normal force of the car acting on the truck. According to Newton's 3rd law, the partner to this force in a 3rd law pair is $\vec{F}_{n\ t-c}$, the normal force the truck exerts on the car.

A: Exploding Carts!

Your teacher has two equal-mass dynamics carts on a track. Cart A has a compressed spring attached. Your teacher will release the spring and we will focus on the interval of time when the spring is expanding and affecting the carts.



1. **Represent.** Draw an ID for the two carts, with each as a separate system. Draw a FD for each cart. The spring force is an *elastic* force.

ID	FDs

2. **Predict.** (*individually)* We want to verify whether Newton's 3rd law applies to this situation. Based on your diagrams, make a prediction comparing the velocity of each cart after the spring is released. Explain what ideas or laws you use.

3. **Test.** (*as a class*) Describe your observations. Do they agree with your predictions?

4. **Predict.** (*individually)* A large mass is added to the cart with the spring. Draw the FDs for when the spring is released. In this situation, how do you think the two cart velocities compare? Explain.

FDs

5. **Test.** (as a class) Describe your observations. Do they agree with your predictions?

6. **Reason.** Marie says, "In this situation, the cart **without** a spring will not exert a force on the cart with the spring. It just sits there passively and gets pushed by the spring." Emmy says, "I think the cart without the spring does push on the other cart." Use your observations to explain who you agree with.

B: The Apple and the Earth

The story goes that our friend Sir Isaac Newton made a great discovery while he was sitting under an apple tree and an apple happened fall down on him.

1. **Represent.** Draw an ID and FD for the apple while it is at rest on the ground. Label each force using the 3rd law notation.

2. **Reason.** Albert says, “The two forces on the FD above must be third law pairs - they are equal in magnitude and opposite in direction.” Do you agree or disagree? Explain.

ID	FD

3. **Represent.** Draw a single ID for the apple and the earth while *the apple is falling*. Circle each object as a separate system. Draw the FDs for each system. (Hint: use the 3rd law!)

4. **Reason.** Use the 1st law to predict the state of motion for each system.

ID	FD Apple	FD Earth

5. **Explain.** One of your predictions probably seems a bit strange. Describe why it seems strange.

6. **Calculate.** The apple has a mass of 0.2 kg. What is the magnitude of the force of gravity it experiences?

7. **Calculate.** Earth has a mass of 6.0×10^{24} kg. Use the 3rd law to determine the magnitude of the force of gravity of the apple acting on Earth. Then use the 2nd Law to calculate the acceleration of Earth.

8. **Reason.** Isaac says, “The earth clearly doesn’t move! I don’t believe that it experiences an equal size force as the apple.” Do you agree or disagree? Explain.

SPH3U: Newton's 3rd Law Homework Name:

A: Physics on Ice

You have brought your little cousin out skating for the very first time. Both of you are standing on the ice wearing skates (no friction) and are facing one another. Your little cousin is a bit timid and needs to hold on to your scarf while you pull.

1. **Represent.** Draw and ID that includes you and your cousin. Draw a FD for you and a FD for your cousin.

2. **Calculate.** Your cousin holds on while you gently pull the scarf with a 6 N force to start her moving. Her little mass is 17 kg. Determine her speed after pulling for 2.0 s.

ID	FD Cousin	FD You

3. **Reason.** Albert says, "I understand why the cousin speeds up – you are pulling on the scarf and she holds on. But I don't predict you will move. Your cousin is only holding on, not pulling. And, in any case, she is much smaller so she couldn't pull you anyways." Do you agree or disagree? Explain.

4. **Represent and Calculate.** Use your actual mass to determine your speed after the same 2.0 seconds of pulling.

B: A Big Push

Your friend is sitting on a skateboard. You stay in place on the road and give her a big push forwards to start her moving. The road is a bit bumpy, so the skateboard experiences some friction. You push on her with a 23 N force. The mass of your friend is 49 kg and the skateboard is 3.1 kg. While you push, your friend accelerates at 0.4 m/s^2. Find the size of **all** the horizontal forces in this situation. Use a solution sheet to show your work, include a **single** interaction diagram showing two systems (you and your friend), and draw a force diagram for each system.

Answers: (A#2) 0.706 m/s, (B) on you (23 N, 23 N), on your friend (23 N, 2.16 N)

SPH3U: Friction Homework!	Name:

A: Friction Lesson Day 1

1. **Represent.** You are reorganizing your room and attempting to move your bed to a new location. You push on the bed, away from the wall, with a 127 N force, but it does not move. Draw an ID and FD for this situation. Write an expression for Newton's 2nd Law in the *x*- and *y*-directions. Use your expressions to find the size of the force of friction.

ID	FD	$F_{net\ x}$ and $F_{net\ y}$

2. You have found a summer job working for Amazon pushing boxes in one of their enormous warehouses. You pushed very hard on one box that turned out to be quite light, so you ended up pushing it much faster than you expected! After it left your hands, it ended up sliding far across the floor before stopping. There are three important events: (1) the box begins to move, (2) you release the box, and (3) the box stops moving.
   (a) **Represent.** Draw an ID and FD for the system of the box during the two intervals.

ID (1-2)	FD (1-2)	ID (2-3)	FD (2-3)

   (b) **Describe.** Explain how you decided to draw the size of the force of friction vectors in your two force diagrams.

B: Friction Lesson Day 2

1. After learning more about friction, you are ready to try moving your bed again. This time, you exert a strong, steady force of 247 N and the bed starts moving. The coefficient of kinetic friction between the bed and floor is 0.53. The bed has a mass of 41 kg. Our goal is to find the acceleration of the bed.
   (a) **Represent.** Draw a force diagram for the bed. (How is this different from Q A#1?)
   (b) **Represent.** We want to build up good habits for showing our understanding when solving friction problems. In each problem, it is always a good idea to carefully write out the *x*- and *y*-components of Newton's 2nd Law. Do this here.

FD

   (c) **Reason.** Friction problems often involve analyzing vertical forces (since the normal force is important) and horizontal forces (since the friction force is important). For each symbol in the two expressions above, we need to decide: do we know this quantity, or can we find it using some other idea? Complete the chart below.

x-direction		*y*-direction	
Quantity	Decision	Quantity	Decision
F_a		F_n	
F_f	use $F_f = \mu_k F_n$, but we don't know F_n!	F_g	
m	given in the problem	m	
a_x		a_y	

   (d) **Reason.** Now we need to make a decision: should we start our solution work with the *x*-or the *y*-component of the 2nd law? In which direction do we have the fewest missing quantities?

   (e) **Complete.** On a separate solution page, complete this problem and the LeBron James question.

Answers: Bed question: a = 0.830 m/s^2, LeBron question: μ = 4.03

SPH3U: Friction

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Athletes are paid millions of dollars every year to endorse fancy shoes. Perhaps they do have some expertise in the matter – maybe the shoes do have an effect on their performance. What makes for a superior shoe? Perhaps it has something to do with friction!

A: Shoe Friction

1. **Reason.** Do you think an athlete wants their shoes to have lots of friction or little? Explain.

2. **Reason.** There are many types of shoes (or footwear) in the world. Which ones do you think have lots of friction? Which have little?

B: The Types of Friction

At the front of the class your teacher has a fairly heavy object and force sensor. Watch as your teacher will gradually exert a larger force on the object using the spring attached to a sensor until the object starts to move. No data will be collected yet.

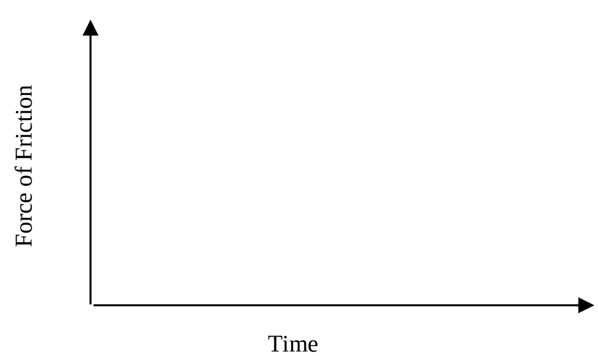
1. **Represent.** For each situation below draw a force diagram for the object. Compare the size of the horizontal forces that may be involved in a particular situation.

(A) Your teacher is not pulling on the object	(B) Your teacher is gently pulling, but it is not yet moving	(C) Your teacher is pulling hard, but it is not yet moving	(D) Your teacher is pulling and it is now moving at a constant velocity
FD	FD	FD	FD
Compare:	Compare:	Compare:	Compare:

2. **Reason.** In which situations above is the force of friction present? What evidence is there? Explain.

3. **Observe.** (*as a class*) Your teacher will now pull on the object while the computer records the data. Sketch a simplified version of the force data on the graph to the right and label the event when the object begins to slide.

4. **Describe**. What happens to the size of the friction force when the object begins to move?



Friction is a contact force that occurs when two objects that are pressed together try to slide against one another. If the surfaces are sliding relative to one another we call the force *kinetic friction* (F_{fk}). If the two surfaces are not slipping we call the force *static friction* (F_{fs}).

5. **Describe.** Label the force diagrams above with the appropriate type of friction.

6. **Reason.** What happens to the size of the force of static friction if we pulled a bit harder and the object still did not move? Explain.

The size of the force of static friction can take a range of values depending on what is happening in the particular situation. $0 < F_{fs} \leq F_{fs\ max}$. There is a maximum possible value for the force of static friction which occurs just before the objects begin to slip. This maximum value is usually greater than the force of kinetic friction.

C: Shoe Physics!

We want to compare the friction of one shoes with another, but there is an important problem:

How does the size of the force of kinetic friction depend on how hard the shoe is pressing into the ground?

1. **Reason.** Which force represents how hard the two objects are pressing against one another? Using the same shoe, how can we change the size of the friction force? Explain.

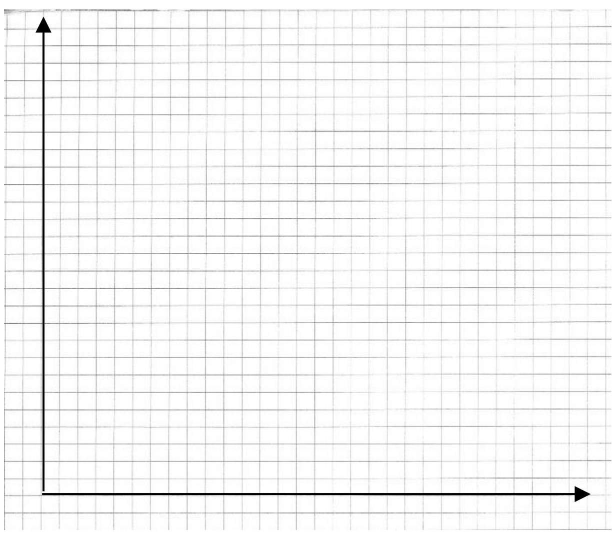
2. **Design an Experiment**. Use a spring scale, your group's shoe and some masses. Describe the procedure of an experiment that will adress the question above. Draw a force diagram for your experiment.

FD

*** check you experiment with your teacher before continuing ***

3. **Observe and Represent.** Collect data according to your procedure. Plot the data <u>comparing the forces</u> on the graph.

Mass (kg)	F_n (N)	F_f (N)



4. **Find a Pattern.** Describe how the size of the force of friction depends on the size of the normal force.

5. **Analyze.** Construct a line of best-fit for your data. Determine the slope of the line. Show your work below.

6. **Report**. Check with your teacher. Record the slope result for your shoe on a white board. Once the class is ready we will share these results. Move on for now.

7. **Interpret.** The value you found for the slope is called the *coefficient of kinetic friction* (μ_k). What characteristics of your experiment do you think affect this value? What is this value a measure of? What would a smaller value for μ_k signify?

8. **Analyze.** Construct an equation for the line of best fit for your graph. Use the symbols F_n, μ_k and F_{fk}.

9. **Calculate.** If a 230 lb (1 kg = 2.2 lbs) basketball player wore your shoe (which may defy other laws of physics!) what would the force of kinetic friction be? Show your work.

E: How the Surfaces Affect Kinetic Friction

1. **Speculate.** Why do you think there is friction between two surfaces?

2. **Predict.** What kinds of surfaces will produce little friction and what kinds will produce great friction?

In the next experiment you will investigate what combination of surfaces will produce the most friction. Make sure that you use a fairly clean surface, otherwise you will be measuring the forces from grinding dirt. Drag the shoe with a bit of extra mass over four surfaces (table, glass, floor, one more of your choice).

3. **Observe.** What is the total mass of your shoe?

4. **Predict.** Choose your fourth surface. Which surfaces do you think will yield high, medium or low friction?

Lower Surface	**Prediction**	**Force of Friction (F_f)**	**Normal Force (F_n)**	**Coefficient (μ_k)**
Table				
Floor				
Glass				

5. **Observe.** Measure the force of friction in each case. Record your results in the chart above.

The *coefficient of kinetic friction* (μ_k) depends on the physical properties (roughness, chemical composition) of the pair of surfaces and is related to the force of friction by the expression: $F_{fk} = \mu_k F_n$. Since the force of kinetic friction is usually different from the maximum force of static friction, there is a separate *coefficient of static friction* (μ_s). We can find the maximum force of static friction using the expression: $F_{fs\ max} = \mu_s F_n$.

6. **Calculate.** Find the coefficient of kinetic friction for the combination of surfaces in your experiment and add these to the table.

7. **Describe.** Were there any surprising results? What does this imply about the floors of professional basketball courts?

8. **Calculate.** LeBron James (113 kg) comes charging down the basketball court, running at 6.3 m/s. He tries to stop moving and ends up sliding along the floor for only 0.5 m. We want to model this situation and find the coefficient of kinetic friction for his shoes and the basketball court floor. Complete this on a solution sheet.

   Ideas to check:
   (1) How does the direction of LeBron's velocity compare with his acceleration?
   (2) While he is sliding to a stop, what objects is he interacting with? Only draw force vectors for those external interactions!
   (3) Work backwards from our goal. We want to find the coefficient. Which equation has μ_k? When do we need to know to find μ_k? So we need to find the … and keep going!