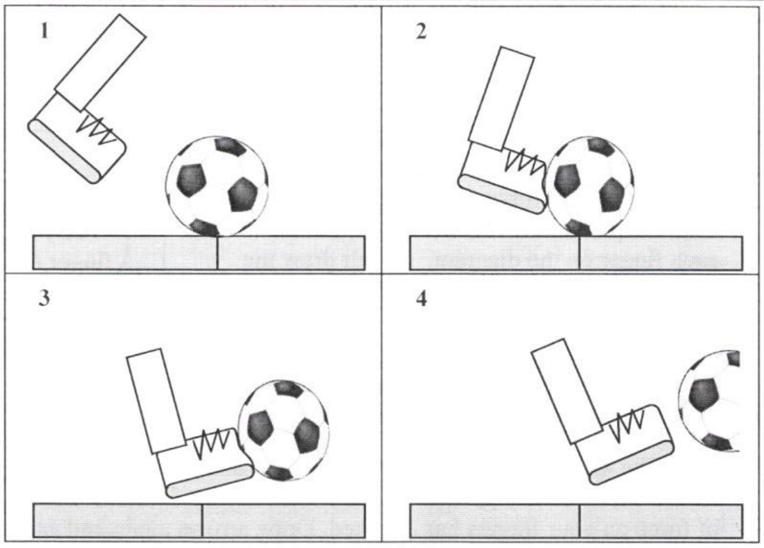
SPH3U: Interactions and Forces

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

A: Thinking About Interactions

Watch the Soccer-Kick-Slow-Motion (Lund) video of a foot kicking a soccer 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 & 3

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

-ball compression -water spray
-foot turn/move

The ball and foot interaction is an example of a *contact interaction*. Such an interaction is only noticeable when 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?

Frames 1 & 2 Between ball and ground

Non-contact interactions can take place when the objects are not in contact. Even though 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.

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

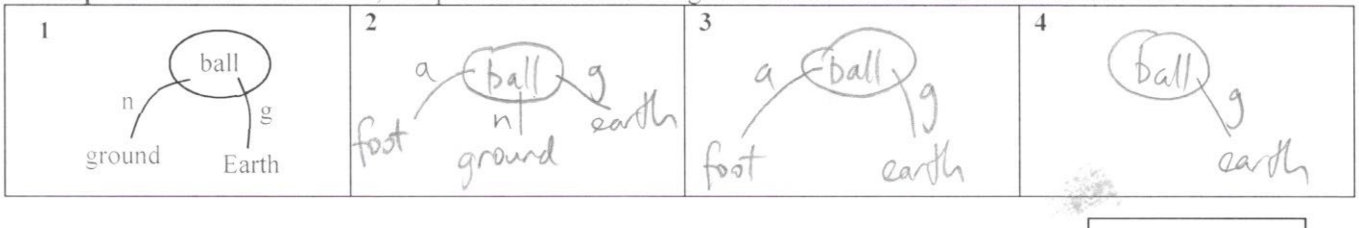
No - when ball is in air it is not affected by the ground

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

Yes - earth pulls ball towards it due to gravity

An *interaction diagram* (ID) represents 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! Note that we consider the ground and Earth as two separate objects since they often participate in interactions in different ways. We show the system object(s) by drawing a circle around them.

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



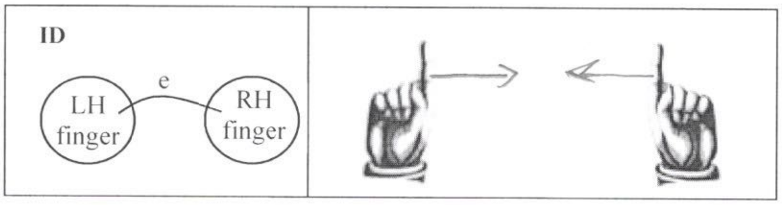
B: A Model Interaction

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.

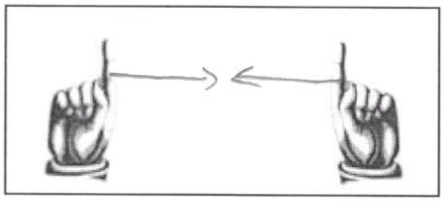
Elastics pushes/pulls fingers towards eachother.

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



Force. 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**.



Lines are longer because the pull is harder.

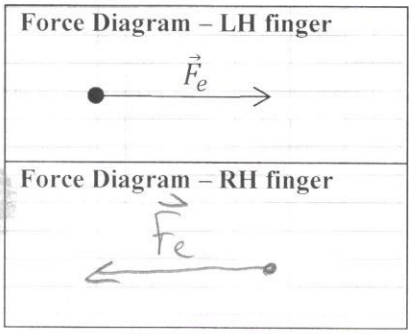
4. **Reason.** What type of quantity best represents a force: a scalar or a vector? Explain.

Vector - how strong the push/pull is, and in what direction. Both are important.

C: Representing Forces

Force Diagram. 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).

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?



Only 1 interaction, so only one force vector arrow in diagram

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

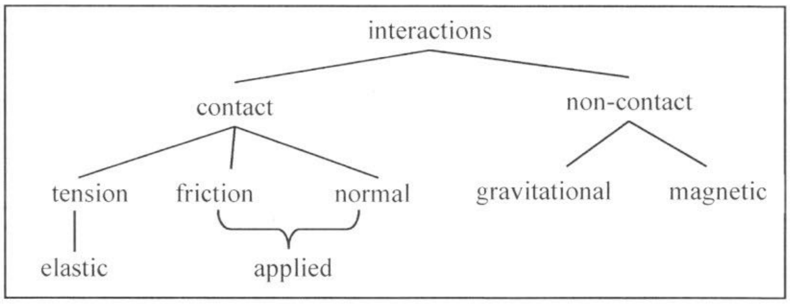
Same length as left finger since pull has same magnitude, but in opposite direction

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.

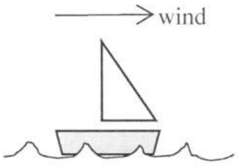
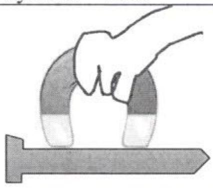
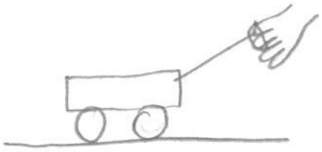
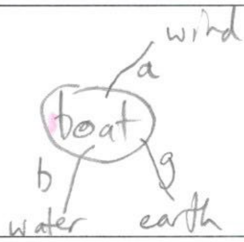
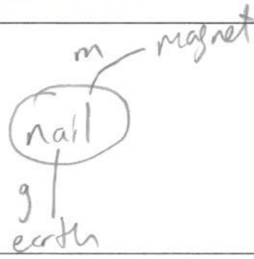
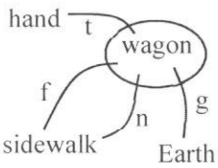
Types of Interactions / Forces

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

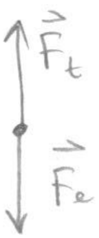
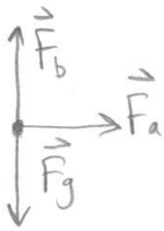
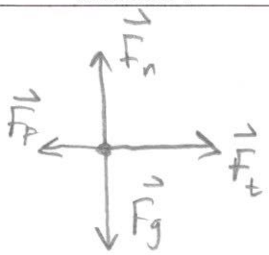


Our contact interactions usually focus on solid objects. It is also possible to have a contact interaction with a fluid. One example of this is **air resistance** (air), and **buoyancy** (b) the interaction responsible for floating.

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

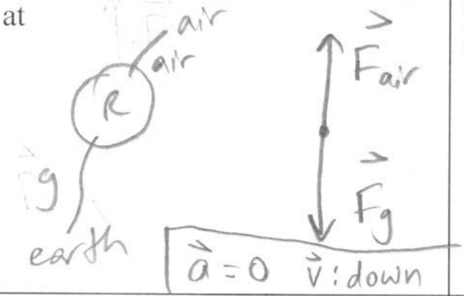
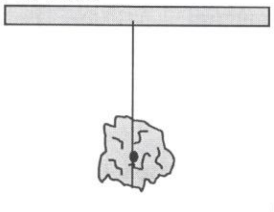
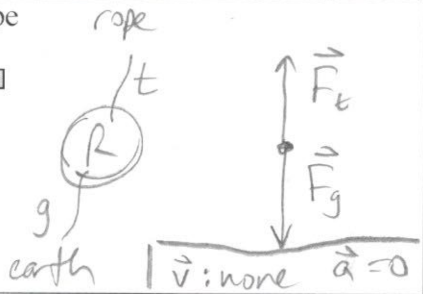
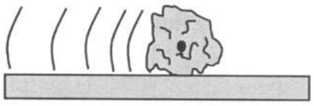
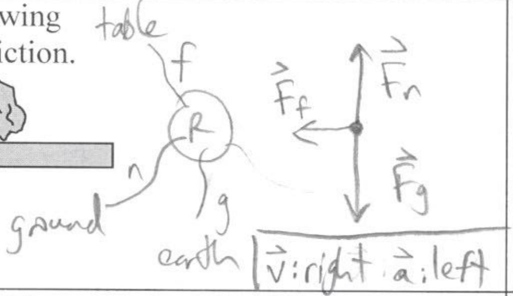
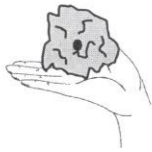
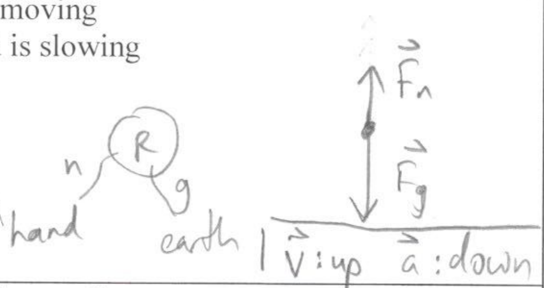
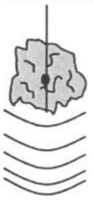
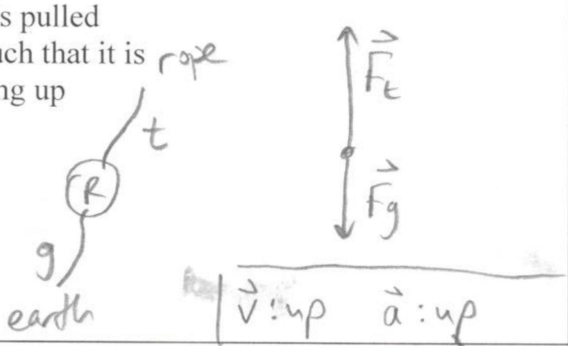
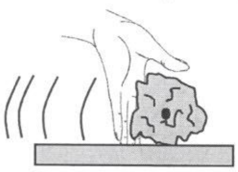
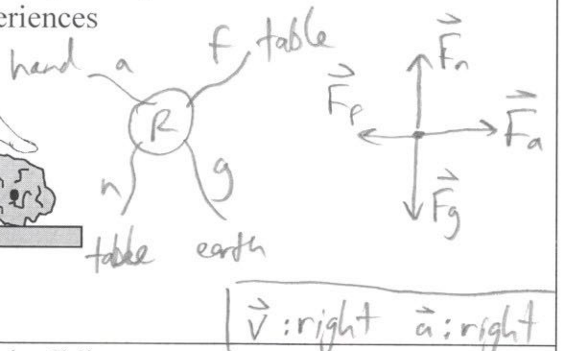
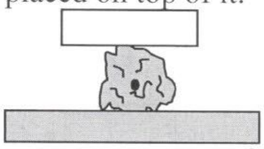
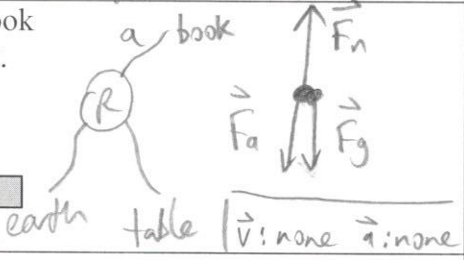
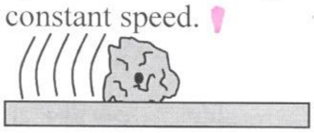
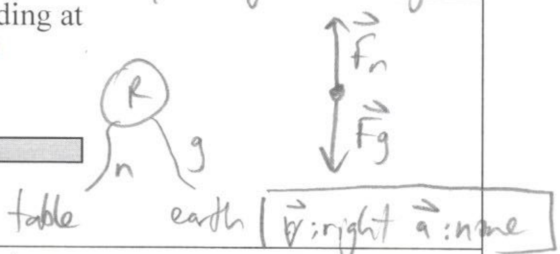
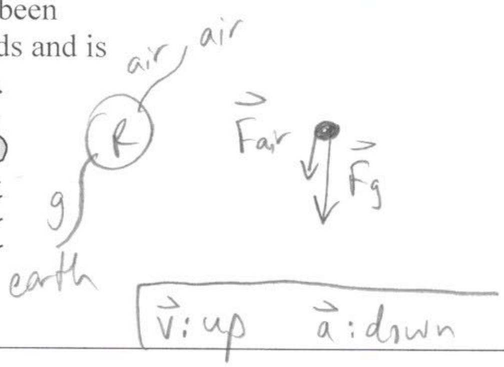
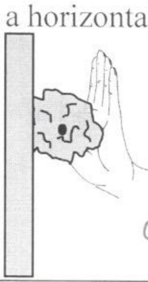
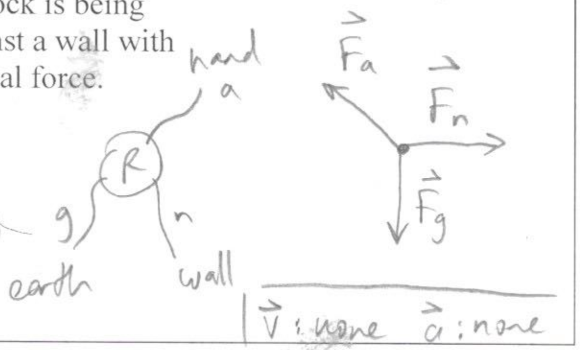
Situation 1	Situation 2	Situation 3	Situation 4
You pull a ball upwards using a string. system = ball	A boat in water is pushed by wind system = boat	a magnet picks up a nail system = nail	a person pulls a wagon along the ground system =
			
			

2. **Represent.** Draw force diagrams (FD) for each situation.

Situation 1	Situation 2	Situation 3	Situation 4
			

SPH3U: Interaction and Force Diagram Review Name:

Draw an interaction diagram and a force diagram for the system of the rock. Label the forces using: $\vec{F}_g$ (force of gravity), $\vec{F}_T$ (force of tension), $\vec{F}_N$ (normal force), $\vec{F}_f$ (force of friction), $\vec{F}_{air}$ (force of air resistance). Indicate the direction of motion and the direction of acceleration.

Situation	ID / FD	Situation	ID / FD
1) A rock is falling at constant (terminal) velocity due to air resistance. 		2) A rock tied to a rope is at rest. 	
3)A rock is slowing down due to friction. 		4) A rock is moving upwards and is slowing down. 	
5) A rock is tied to a rope and is pulled upward such that it is accelerating up 		6) The rock is speeding up and experiences friction. 	
7) A rock has a book placed on top of it. 		8) The rock is sliding at constant speed. 	
9) A rock has been thrown upwards and is slowing down. 		10) The rock is being held against a wall with a horizontal force. 	

SPH3U: What is the Effect of a Force?

What happens when a single constant force acts on an object? Perform your own experiment to find out. Ideas are: pushing a sibling on a bicycle, pulling a sibling on a skateboard, …)

A: The Steady Push or Pull

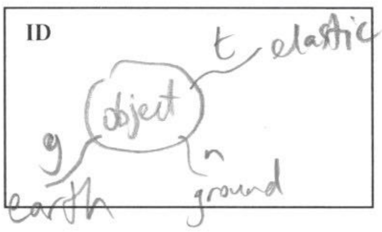
1. **Prediction**. How will an object move when you exert a constant horizontal force (a steady push or pull) on it?

   Might move at a steady speed?

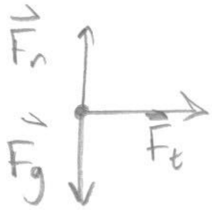
2. **Design.** Test and describe what you did, your observations and how you exerted a constant horizontal force.

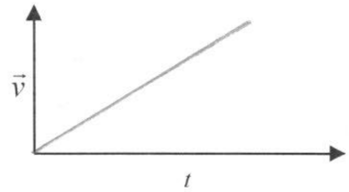
   Attach an object to elastic and pull. Length of elastic should stay constant

3. **Represent.** Draw an interaction diagram for your system while you are exerting the constant force. Then draw a motion diagram and a velocity graph and a force diagram (FD). Label the events (1) starts the push / pull (2) stop the push / pull.



FD:





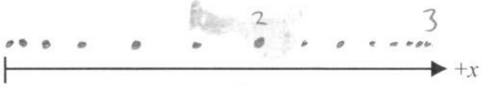
B: Let Go

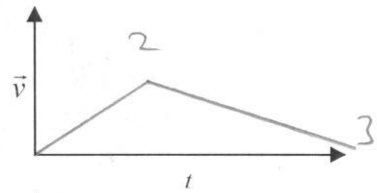
After your object is in motion, stop exerting your force.

1. **Observe.** Describe the motion of your object **after** it has been released.

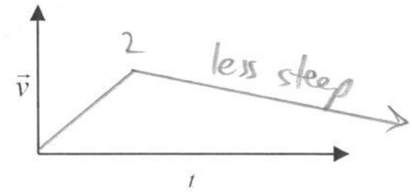
   Stops accelerating but still has velocity. Slows down

2. **Represent.** Complete the motion diagram and velocity-time graph diagrams. Label two events on each: (2) stop the push / pull and (3) the object comes to rest.



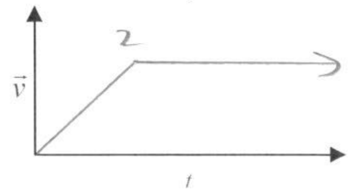


3. **Reason and Represent.** Imagine you could reduce friction a bit. Explain how the motion after it is released would be different. Sketch a velocity graph for this imaginary situation and explain how it appears different from the previous velocity graph. Velocity would decrease more slowly



4. **Reason and Represent.** Now imagine you remove **all** sources of friction. After you stop pushing / pulling, what would you observe in this very special situation? Sketch a velocity graph. In this situation what horizontal forces are acting on the cart?

   → would keep moving at max speed. No horizontal forces are acting.



C: Summary

1. **Reason.** Describe the motion that results from an object experiencing a single constant force.

   It accelerates in the same direction as the applied force.

SPH3U: The Net Force

A car driving down the road experiences many forces at the same time. What happens in such a case? Use the Forces and Motion Basics (Net Force) simulation with 2 horizontal forces pulling on the cart (https://phet.colorado.edu/en/simulation/forces-and-motion-basics). Assume friction is very small (the size of friction is zero).

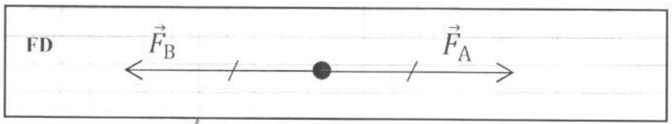
A: Two Balanced Forces

Exert two equal-sized forces on the cart, but in opposite directions.

1. **Observe.** Describe the motion of the cart.

Does not move

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



They have the same magnitude

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

3. **Explain.** Below are vector and scalar equations for the net force in the *x*-direction experienced by the cart. Why do these make sense?

$\vec{F}_{net\,x} = \vec{F}_B + \vec{F}_A$

↳ Because vectors, one of these will be negative and so $\vec{F}_B$ and F_A will cancel out

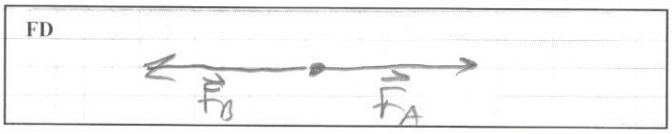
$F_{net\,x} = -F_B + F_A$

↳ Because scalars, both F_B and F_A will be positive. So negative sign needed for $F_{net\,x}$ to be zero.

B: On the Move

What will happen to a cart that is already moving if it experiences balanced forces?

1. **Represent.** Draw a FD for the cart. Label the two forces. Assume F_A = 50 N and F_B= 50 N.



2. **Calculate.** Write a net force equation in the *x*-direction and calculate the result.

$\vec{F}_{net} = \vec{F}_A + \vec{F}_B$

$= 50N + (-50\,N) = 0$

$\vec{F}_{net\,x} = 0$

3. **Test.** Describe your observations. Explain.

turn on speed, add person

The cart continues travelling at the same speed it was travelling when the balancing applied force is added.

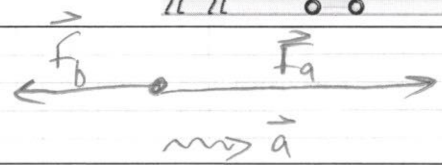
C: Net Force is Not Zero

Now increase the size of one of the forces. F_A = 100 N, keep $\vec{F_B} = -50$

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

   F_A is twice as long

FD



2. **Calculate.** Write a net force equation and calculate the result.

   $\vec{F}_{net} = \vec{F_a} + \vec{F_b} = 100\,N + (-50\,N) = 50\,N$ [RIGHT]

Unbalanced Forces. If the net force is not equal to zero, we say that the forces acting on the object are *unbalanced.*

3. **Test.** Use a timer to determine how long it will take for the tug-of-war to end.

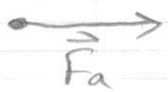
   ~9.7 s

Acceleration Vector. If a system accelerates, draw a wiggly acceleration vector ($\vec{a}$ ⤳) that points in the direction of the acceleration alongside the force diagram. Check your previous force diagrams and add an acceleration vector.

4. **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.

   $\vec{F_a} = 50\,N$ [RIGHT]

FD



5. **Test.** The cart now experiences a single force equal to the net force from before. Run the simulation, and again use your timer to determine how long it takes. Compare your result to the time from #3 above.

   approx. same time as above.

D: The Forces-Motion Catalogue

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

State of Force	**Net Force** (circle one)	**State of Motion (constant / accelerating)**
No forces at all	(zero) / non-zero	1) if at rest, stays at rest
		2) if moving, continues moving
Balanced forces (two or more)	(zero) / non-zero	1) if at rest, stays at rest
		2) if moving, continues moving
One single, unbalanced force	zero / (non-zero)	accelerating in direction of force
Unbalanced forces (two or more)	zero / (non-zero)	" " " " net force

First Law of Motion

SPH3U Homework: The Net Force　　　　Name:

1. For each force diagram, decide if the forces appear to be balanced or unbalanced. Write the expression for the net force in the *x- or y*-direction. Use the directions right or up as positive. What type 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	$\vec{F}_a$ ← • → $\vec{F}_f$	$\vec{F}_a$ ← • → $\vec{F}_t$	$\vec{F}_n$ ← • → $\vec{F}_a$	$\vec{F}_a$ ← • → $\vec{F}_t$ → $\vec{F}_f$
Balanced?	unbalanced	unbalanced	balanced	unbalanced
$\vec{F}_{net\,x}$	$\vec{F}_{net\,x} = \vec{F}_f + \vec{F}_a$	$\vec{F}_{net} = \vec{F}_f + \vec{F}_a$	$\vec{F}_{net\,x} = \vec{F}_n + \vec{F}_a$	$\vec{F}_{net\,x} = \vec{F}_a + \vec{F}_t + \vec{F}_f$
Motion?	positive accel.	negative accel	at rest/constant v	positive acceleration

FD	$\vec{F}_t$ ↑ • ↓ $\vec{F}_g$	$\vec{F}_n$ ↑ • ↓ $\vec{F}_g$	$\vec{F}_n$, $\vec{F}_t$ ↑ • ↓ $\vec{F}_g$	$\vec{F}_a$ ↑ • ↓ $\vec{F}_g$
Balanced?	balanced	unbalanced	balanced	unbalanced
$\vec{F}_{net\,y}$	$\vec{F}_{net\,y} = \vec{F}_t + \vec{F}_g$	$\vec{F}_{net\,y} = \vec{F}_n + \vec{F}_g$	$\vec{F}_{net\,y} = \vec{F}_g + \vec{F}_t + \vec{F}_n$	$\vec{F}_{net\,y} = \vec{F}_g + \vec{F}_a$
Motion?	at rest/constant v	negative accel.	at rest/constant	negative acceleration

2. Two forces act in opposite directions on an object, F_R to the right and F_L to the left. Indicate the direction of the acceleration with a wiggly acceleration vector. Compare the size of the two forces. Draw a force diagram.

Motion Diagram	1 • • • • • • 2 →	2 • • • • • • 1 →	1 •• • • • • 2 →	2 •• • • • • 1 →
Accel.	none	← (wiggly)	(wiggly) →	(wiggly) →
Compare	$F_L = F_R$	$F_L > F_R$	$F_L < F_R$	$F_L < F_R$
Force Diagram	$\vec{F}_L$ ← • → $\vec{F}_R$	$\vec{F}_L$ ← • → $\vec{F}_R$	F_L ← • → F_R	F_L ← • → F_R

3. Each situation is described by a force diagram and an initial velocity. Draw a motion diagram for each situation. You may assume that the object does not change direction.

FD	$\vec{F}_t$ ← • → $\vec{F}_a$	$\vec{F}_a$ ← • → $\vec{F}_t$	$\vec{F}_a$ ← • → $\vec{F}_f$	$\vec{F}_n$ ← • → $\vec{F}_a$
v_1	0	Negative	positive	positive
Motion Diagram	1 •• • • • • 2 →	2 • • • • • 1 →	1 • • • • •• 2 →	1 • • • • • 2 →

SPH3U: The Force of Gravity!

How does an object's mass affect the size of the force of gravity it experiences? Let's find out. Your teacher will show you a spring scale, but you will collect data using a Gizmos applet. Follow the instructions to the right to find the activity.

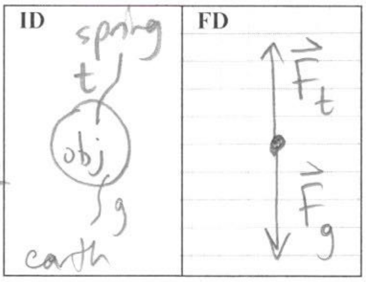
Visit www.explorelearning.com
Enter class code MZTPMM
Make an account (if needed)
Go to My Classes > SPH3U
Weight and Mass

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?

Non-contact - objects experience even when not touching earth

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



The "pull" of the tension will counteract the "pull" of gravity exactly, since the object is not moving... balanced forces.

3. **Design & Observe.** We want to know how the mass of the object affects the magnitude of the force of gravity that it experiences. Add a variety of known masses to the spring scale in the activity, and complete the table of values below.

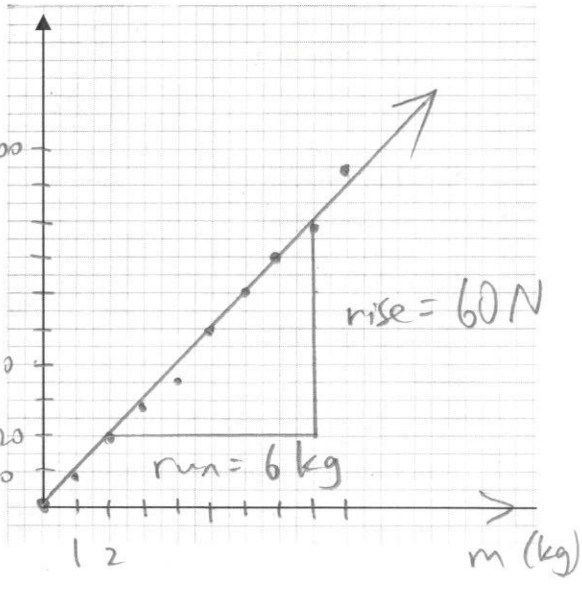
4. **Analyze.** Decide which variable is the dependent one. Plot your data on the graph. Use the shape of the graph to describe how the force depends on the mass.

Mass (kg)	Force of Gravity (N)
0	0
1	8
2	20
3	28
4	35
5	50
6	60
7	70
8	78
9	95

5. **Calculate.** Determine the slope of your graph, including units.

$m = \frac{rise}{run} = \frac{60\ N}{6\ kg}$

$m = 10\ N/kg$



The slope of your graph gives a very important quantity, the gravitational field strength $\vec{g}$. It tells us how much force the earth's gravity exerts on each kilogram of matter in an object. The exact value depends on many factors including geographic location, altitude, and planet. The accepted value for your location is: 9.8 N/kg [down]. We will use 10 N/kg [down]

6. **Analyze.** Write an equation for your line of best fit – use the symbols F_g and m.

$y = mx$ $\quad F_g = 10m$ N [down]

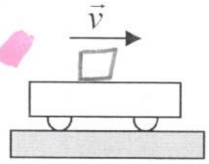
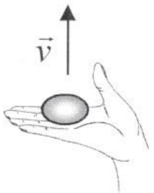
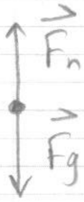
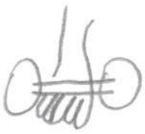
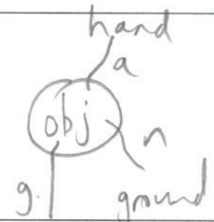
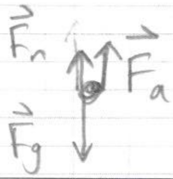
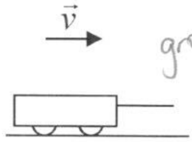
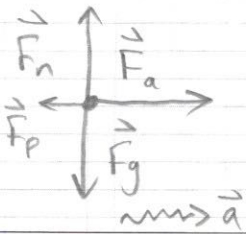
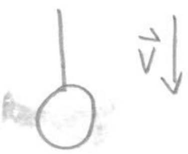
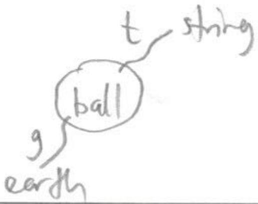
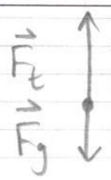
7. **Apply.** Use your new equation to determine the size of the force of gravity acting on a 1.5×10^3 kg car.

1.5×10^3 kg = 1500 kg

$\vec{F}_g = 10(1500) = 15000$ N [down]

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. A weight rests on top of the cart. System = cart+weight				$\vec{F}_{net\ x} =$ 0 N $\vec{F}_{net\ y} =$ 0 N
2	A tasty chocolate in your hand is moving upwards with a constant speed. System = chocolate				$\vec{F}_{net\ x} = 0$ N $\vec{F}_{net\ y} = 0$N
3	You pull upwards on a heavy dumbbell, but it doesn't move. System = dumbbell				$\vec{F}_{net\ x} = 0$N $\vec{F}_{net\ y} = 0$N
4	You pull along the horizontal handle of a wagon. It travels along the rough ground and speeds up. System = wagon				$\vec{F}_{net\ x} = \vec{F}_a + \vec{F}_f$ $F_{net\ y} = 0$
5	You lower a ball using a string. It slows down. System = ball				$\vec{F}_{net\ x} = 0$ $\vec{F}_{net\ y} = \vec{F}_g + \vec{F}_t$

2. **Calculate.** The chocolate in question #2 has a mass of 20 g. What is the size of the upwards force it experiences?

$\vec{F}_g = m\vec{g}$ $\quad \vec{F}_g = (0.02\text{ kg})(10\text{ N/kg})$ [down]

$20\text{g} = 0.02\text{ kg}$ $\quad \vec{F}_g = 0.2\text{ N}$ [down]

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

$\vec{F}_g = m\vec{g}$

$= (10\text{ kg})(10\text{ N/kg})$

$= 100\text{ N}$

Since $\vec{F}_{net\ y} = 0$, then $\vec{F}_g = \vec{F}_n + \vec{F}_a$

$100\text{ N} = \vec{F}_n + 10\text{ N}$

$\vec{F}_n = 90\text{ N}$

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

$F_{net\ x} = 30\text{ N}$ $\quad F_{net\ x} = \vec{F}_a + F_f$

$30\text{N} = \vec{F}_a + 10\text{ N}$

$\vec{F}_a = 20\text{ N}$ [right]