

Dynamics – Freefall, Apparent Weight, and Friction (Honors)

PURPOSE

- To investigate the vector nature of forces.
- To practice the use free-body diagrams (FBDs).
- To learn to apply Newton’s Second Law to systems of masses.
- To develop a clear concept of the idea of apparent weight.
- To explore the effect of kinetic friction on motion.

EQUIPMENT

Virtual Dynamics Track VPL Grapher PENCIL 

See Video Overview at: http://virtuallabs.ket.org/physics/apparatus/02_kinematics/

EXPLORE THE APPARATUS

Open the Virtual Dynamics Track. You’ll see the low-friction track and cart at the top of the screen. At the bottom you’ll see a roll of *massless* string, several masses, and a mass hanger. Roll your pointer over each of these to view the behavior of each. Note the values of the masses. Also note that the empty hanger’s mass is 50 g. If you move your pointer over the cart you’ll see that its mass is 250 g.

- Drag the cart near the left end of the track.
- Drag the spool of *massless* red string somewhere just to the right of the cart. (Fig. 1a.) Release it by releasing your mouse button. A segment of string will attach to the cart and find its way over the pulley. A small loop (Fig. 1b.) will form at its lower end.
- Drag the mass hanger until its curved handle is a bit above the loop (Fig. 1c). Release your mouse button and the hanger will attach. (Fig. 1d) The cart will take off. It’s alive! Drag the cart back and forth. Everything should work just as you’d expect. Give it a toss or use Go→ to launch it with a known initial negative velocity.
- Check out the Brakes On/Off toggle button.
- Try Reset All.
- Reattach the string and hanger.

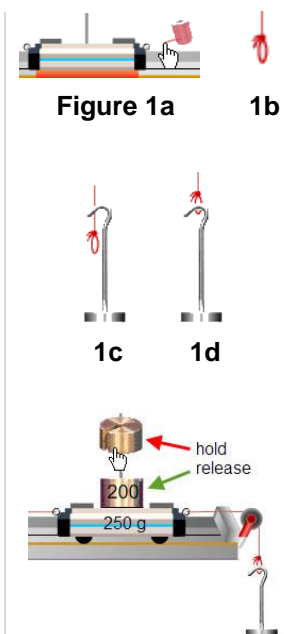


Figure 2

Turn on the brake and move the cart near the middle of the track. (Just so you can see the hanger.) You can add to, and remove masses from, the cart or hanger as needed. Drag the largest mass, 200 grams, and drop it when it’s somewhat above the base of the spindle of the cart. (Fig. 2) Drag a 50-g mass onto the hanger.

We refer to this group – cart, string, and hangers – as a **system**. You can actually call any group of objects a system – the solar system for example. We’re going to investigate how our cart, string, and hanger move together as a system. The massless string transmits forces between the cart and hanger.

- Toss the cart around and notice how it moves. Experiment with a variety of masses on both the cart and hanger. Investigate what determines the system’s acceleration. You know how to *add* masses. You can *remove* them just by clicking. Try this. Turn on the brakes to hold the cart still and then add two masses to the cart and to each hanger. Click once on each of the three. The top mass will disappear in each case. Another three clicks will empty them all. Clicking on an empty hanger will remove it. The Reset All button will then remove the massless string.

We'll now use this and other arrangements of masses to look at various systems, how they move, and why. We'll quantify what we find using Newton's second law, $\Sigma \vec{F} = m\vec{a}$, where $\Sigma \vec{F}$ is the net, external force on the system, m is the total mass of the system, and \vec{a} is the acceleration of the system.


Restore your system to its simplest configuration – empty cart, string, and empty hanger. Turn on the brake and move the cart near the left bumper.

PROCEDURE

IA. Drawing force vectors

We've found that writing down what we know and want to know is essential to successful problem-solving. But with forces, there's the added directional information that's best described with a figure. Figure 2 is a nice representation of what our apparatus looks like, but it doesn't show us the forces. Drawing force vectors can make it easier to identify the forces acting on systems. They also guide us in deciding which forces that go into the equation $\Sigma \vec{F} = m\vec{a}$.

Free-body diagrams

Click  to turn on "Dynamic Vectors." You'll want to leave Dynamic Vectors on most of the time during this lab. Adjust the check boxes in the apparatus to match Figure 3. You should now see something like Figure 4. (Some extra labels have been added for clarity.)

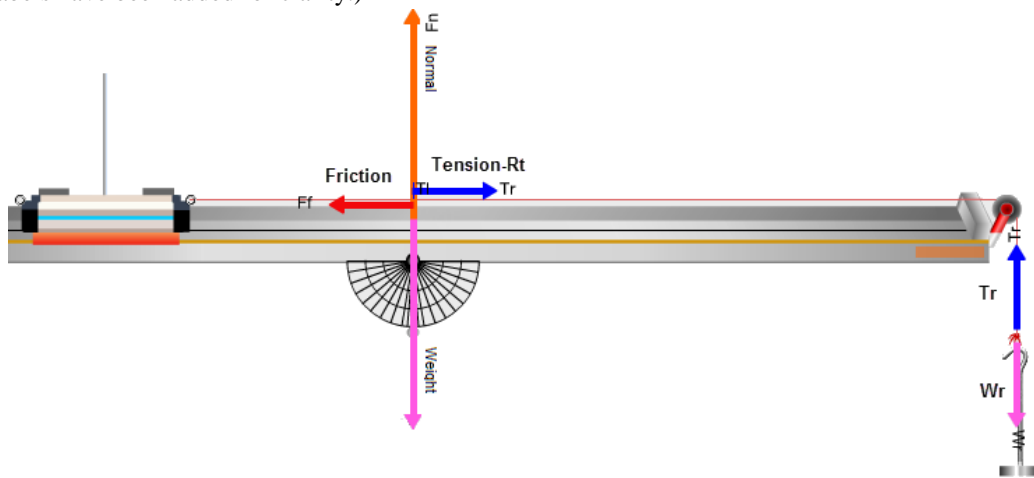


Figure 4 – Dynamic Vectors

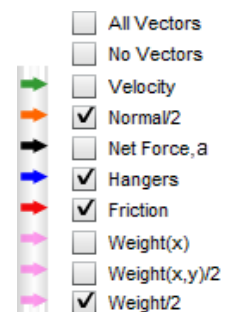


Figure 3 – Vector Display Controls

The two groupings of force vectors are actually dynamic versions of **free-body diagrams (FBDs)**. In an FBD we draw an object, represented by a dot, with scaled vector arrows radiating from it indicating the magnitude and direction of all the forces acting on it. Our dynamic FBDs don't include the dots but the objects represented are the cart and two hangers. The hanger FBDs move along with the hangers. The FBD for the cart sits at the midpoint of the track. (An earlier version had it attached to the cart but it was maddening to try to follow it as it moved.)

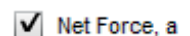
The cart's vector cluster can also include the velocity which is of course not a force. It can also include "Net Force, a " which represents the net force on the entire system and the system acceleration. None of these will be part of an FBD since they are not "external forces acting on an object." They're provided because they're very useful, as you'll see.

Cart Forces

In the vertical you see the normal force, N , and the weight, W , which are equal and opposite. Thus there is no vertical acceleration by the cart, and there won't ever be with a level, indestructible track. (F_n and W are drawn half scale as $F_n/2$ and $W/2$ because they're so large and tend to go off the page.) Uncheck the Normal force and weight vectors.

In the horizontal you see the tension in the (right) string, T_r and the friction force, F_f . They're also equal (while the cart is at rest) but opposite. Thus there is currently no acceleration in the horizontal because the brake is holding things at rest.

Turn on the Net Force vector so that you can monitor ΣF and the acceleration once the cart starts moving.



You'll just see the label " F_{net}, a " but no vector arrow so far.

Hanger Forces

The forces on the mass hanger are the opposing forces T_r , and W_r . W_r is the weight of the right mass hanger. T_r is again the tension in the string. For a massless string, the tension is the same throughout. (For a non-massless string the trailing end will have less tension than the leading end. We'll discuss that no further!) It's important that you understand that we use the term tension in two ways. In everyday use we think of the tension as the tautness of a string. That tautness is caused by forces pulling on each end. The reaction force by the strings' ends on the cart and hanger are also referred to as the tension. So we say that the tension force provided by the string acts equally (for our massless string) on both the cart and the hanger. So the pair of T 's will always represent equal magnitude forces acting on the objects the string is attached to. Make sure that you see how that's represented in Figure 4.

The System

Newton's second law, $\Sigma \vec{F} = m\vec{a}$, describes the effect of a net force on an object or group of objects, referred to as the **system**, that move with some acceleration, \vec{a} , due to the net, external force, $\Sigma \vec{F}$, acting on the system. The mass, m , is the total mass of the system.

For a system of more than one object Newton's 2nd law works for the whole group or any part of the group.

- In Figure 5 we might consider the cart and hanger as a system and then consider the net, external force on that system, and the mass of the system.
- We might also say, "let's consider just the cart as the system." We'd then look at the forces on the cart, the cart's mass, etc.
- In this lab we'll think of the cart and hangers as "the system" unless stated otherwise.

Whichever way we go about it we'll find the same acceleration since all parts have the same acceleration. We will have to deal with the change in direction due to the pulley. More on that soon.

The Net Force

In Figure 4 the cart-hanger system remained at rest because of the brake which exerts a friction force, F_f , which changes to match any amount of weight that can be added to the hanger. When you release the brake the vectors should change to look like Figure 5. Try it at few times. There is now a net force so there will be an acceleration. Try turning the brake on and off and notice how the forces change. You can also just hold and release the cart with the mouse. You're sort of acting like a brake but no vector will be shown to represent this.

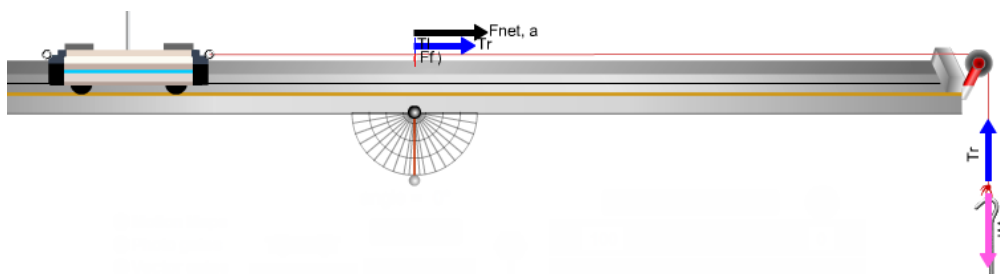


Figure 5 – The Net Force

IB. Accelerated system of a cart on a level track with mass hanger and no friction

Let's see how we can use FBD's to help us think about a simple system and then build some equations to describe it mathematically.

Set up the system shown in Figure 6. You need a level track with an empty hanger on the right and an extra 200 g on the 250-g cart.

What would be the acceleration of the cart when it's allowed to move freely? To use Newton's second Law we need to know the mass of, and net force on a system.

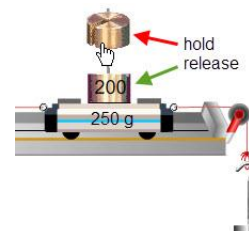


Figure 6 – Adding Cart Masses

The system we've chosen has two parts that move independently and each part has its own mass and forces acting on it. But toss the cart a few times. Some observations:

1. Although the cart and hanger are moving in different directions, they're otherwise moving identically. For example, when the hanger is moving at, say, 2 m/s, the string ensures that the cart is also moving at 2 m/s.
2. This also includes direction, if you don't mind a minor 90° bend in the middle. Motion left and right by the cart is the same as motion up and down by the hanger. The pulley is just redirecting it. **We'll work with the bendy direction and say that the positive direction is as shown in Figure 7. For the cart, the +x direction is to the right. For the hanger, it's downward.**
3. We don't know the net force on either object but if we look at the cart, string, and hanger as one system, there is only one unbalanced, external force acting on the system – the weight of the hanger. (The cart's weight and normal force cancel.) So our system behaves the same as the one shown in Figure 8 where the masses of the cart and hanger make up the total mass and the weight of the hanger is the net force.

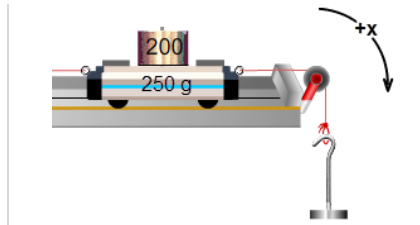


Figure 7 – the “x-direction”

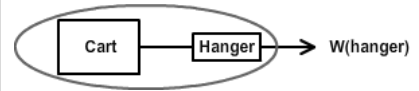


Figure 8 – The System Mass
(Note the cool optical illusion. The squares don't look quite square.)

OK, let's use the cart and hanger as our system. Think about these three questions.

- a. $m_{system} = ?$
- b. $\Sigma F_{on\ system} = ?$
- c. $a_{system} = ?$

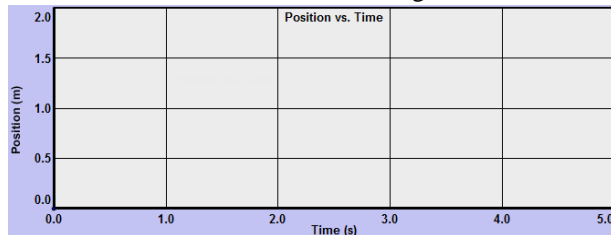
- a. Clearly, both the cart and hanger are accelerating. So $m_{system} = 450\text{ g} + 50\text{ g} = 500\text{ g} = .500\text{ kg}$ (Note the mks units.)
- b. There are three forces present: T_r , T_l , and W_r . But both T_r 's are internal to the system. The only external force is W_r .
 $W_r = m_{hanger} g = .050\text{ kg} \times 9.80\text{ N/kg} = .49\text{ N}$
- c. $a = \Sigma F / (m_{cart} + m_{hanger}) = .49\text{ N} / .500\text{ kg} = 0.98\text{ m/s}^2$

Confirm these results experimentally.

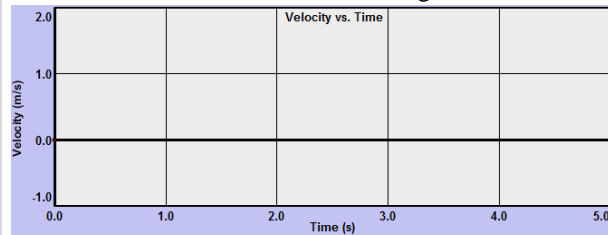
Using your virtual apparatus, confirm your results. If you recall, in the acceleration lab you found the acceleration of a cart from the slope of a velocity, time graph. That would be a good method to use here.

4. With the brake on, turn on the sensor. Then release the brake. Turn off the sensor when the cart reaches the bumper.
5. Copy data to clipboard and use Ctrl+V to paste it into Grapher.
6. Turn on Graph # 2 to display the $v-t$ graph. (Turn on Graph #3 just to shrink Graphs #1 and #2.)
7. Sketch the graphs you obtained from **Grapher** below
8. Take Screenshots of your $x-t$ and $v-t$ graphs. Save them as “Dyn_IB1a.png” and “Dyn_IB1b.png”, print them out, and paste them in the space provided.

IB1a. Observation $x-t$ for cart and hanger



IB1b. Observation $v-t$ for cart and hanger



9. Acceleration: slope from $v-t$ graph _____ m/s^2
10. Compare the theoretical (calculated value) above in #4c.
Percentage error _____ %

Show calculations for percentage error here. Use the calculated value as the theoretical value.

Summary

The hanger's weight, W_r , is gravity's pull downward on the hanger, so it's an **external** force. That is, it's a force exerted on the system from outside.

The two tension forces, T_r , are **internal** to our cart-string-hanger system, so they don't affect its motion. The system does include the string. The pulley changes the direction of the tension force but doesn't affect its magnitude.

The net external force, F_{net} is equal to W_r . Observe the moving cart and note that the lengths of their vectors are equal.

Just to make sure you understand, the net force is not a particular force acting on our system. It's the sum of all the external forces. Also, we often leave off the term "external" and just say net force.

IC. Accelerated system of a cart on a level track with 2 mass hangers and no friction

How about adding a mass hanger on the left side? Set up your own arrangement and repeat the procedures in part Ib. Add masses to each hanger, choosing your hanger masses so that there will be a non-zero acceleration.

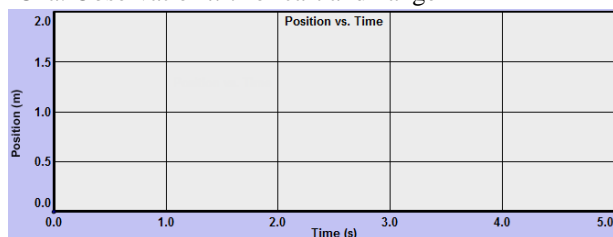
In the space below #3, provide a well-organized display showing

1. all your data from the apparatus. This would just be all your masses.
2. all your calculated values. This would include your total mass, all external forces affecting the acceleration, the net force on the system, calculated acceleration from $\Sigma F = ma$, experimental acceleration from the slope of your $v-t$ graph, and the percentage error between the calculated (theoretical), and experimental values for your acceleration.
Be careful with units!
3. all calculations involved in item #2.

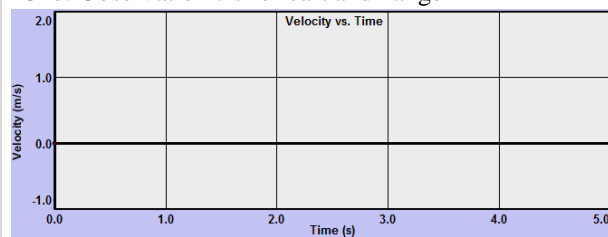
Use this area to lay out your work, then type your work into the space provided in WebAssign.

Take Screenshots of your $x-t$ and $v-t$ graphs, save them as "Dyn_IC1a.png" and "Dyn_IC1b.png", print them out and paste them in the space provided.

IC1a. Observation $x-t$ for cart and hanger



IC1b. Observation $v-t$ for cart and hanger



IIA. Freefall Acceleration

We've found that all bodies in free fall have the same downward acceleration, g . Let's use our apparatus to find the value of g for a falling mass hanger. **We need a system of one object – the mass hanger.** Hmm. You can't have a mass hanger without a string to attach it to. And all position measurements are associated with the cart, not the hanger. So we need a cart, but not its mass. We need a sort of vacant, empty, soulless, massless cart.

What we need is a *Zombie CART!* Or as Dr. Seuss would call it, little cart Z .

Set up the dynamics track with an empty cart and hanger. Drag the cart near the left bumper and let it go.

That looks OK, but as noted, the hanger is not really free-falling? It's dragging the cart behind it.

Put on the brake and move the cart near the left end of the track. Now click on the Z-cart icon. The cart will become translucent indicating that it has become massless. Zoom! Clicking the Z-cart icon again will restore its mass. Repeat in and out of Z-mode to convince yourself that the whole system seems to move with a greater acceleration, possibly equal to g , when the cart's mass is eliminated. That's because the system here is really just the mass hanger. So the Z-car is doing just what we want it to do. It's collecting sensor data without contributing any mass.

Try this. Turn on the motion sensor and record the motion in normal mode (hanger + normal cart) in one color. Then select another line color and try a Z-mode run. Do the graphs show different accelerations? They should.

1. You may have noticed that the brake doesn't work in Z-mode. Check it out. Why doesn't it work in Z-mode?

2. Since we can eliminate the mass of the cart with z-mode, we can now look at the motion of the freely falling hanger. Find its acceleration as follows.

- Set Recoil to zero to eliminate bouncing.
- Use normal mode (not Z-mode) Empty cart and hanger. Cart near the left end of the track with the brake on.
- Turn the Motion Sensor on.
- Click on the Z-icon. The cart should quickly accelerate to the right end of the track.
- Turn the Motion Sensor off.

3. Let's find the **approximate** acceleration using one of our kinematics equations. The cart and hanger travel with identical motions. We'll find the acceleration of the cart which is the same as that of the hanger. For the cart we can say

$$\Delta x = v_o t + \frac{1}{2} a \Delta t^2$$

But if we choose our initial time, t_1 , as just about when we turn off the brake, $v_o \approx 0$. So

$$\Delta x \approx \frac{1}{2} a \Delta t^2 \quad (10)$$

We can get Δt and Δx from the Dynamics Track data table. Look at the position values. They're all the same until you turned off the brake. Find the last data pair before the cart starts moving. Ex. $x = 0.098, 0.098, \dots, \mathbf{0.098}, 0.108 \leftarrow$ **the last 0.098.**

This will be our initial value, when $v_o \approx 0$. The cart's motion actually started between this instant and the one after it, but we'll get a fairly accurate number if we ignore this error.

- Record this first data pair as t_1 , and x_1 in Table 1.
- Scroll through the data to find a point somewhat before the cart hit the right bumper. That is before the position stops changing. Record the data for this point as t_2 , and x_2 in the table.
- Calculate and record Δx , and Δt .
- Calculate and record the acceleration in Table 1 using Equation 1.

Time passes...

Sample Data

Table 1 Free-fall acceleration (for parts IIA and IIB)					
Mass, m (kg)	Time, t (s)	Position, x (m)	Δt (s)	Δx (m)	a (m/s^2)
.050	$t_1 =$	$x_1 =$			
	$t_2 =$	$x_2 =$			
.100	$t_3 =$	$x_3 =$			
	$t_4 =$	$x_4 =$			

4. For your system (mass hanger), $m =$ ____ kg, $\Sigma F = mg =$ ____ N, theoretical $a = F/m =$ ____ m/s^2

5. Show calculations using Equation 1 for the acceleration with just the mass hanger.

6. Show calculations for percentage error here. Use the F/m value for acceleration as your theoretical value.

Your result should be somewhat different than the theoretical value since the timer was already counting when we started the cart so the time when the cart actually started was most likely in between two time readings.

IIB. Freefall – the effect of the weight of the falling object on its acceleration

Throughout most of recorded history it was believed that the heavier a body is the faster it will fall. (Those of that opinion also didn't quibble over the definition of the terms "fast" and "slow." Did it correspond to velocity or acceleration?)

At first glance $F = ma$ would seem to support their theory since the acceleration is directly proportional to F . Thus a heavier body would seem accelerate faster than a lighter body. Let's test this old theory.

In part IIA you observed the fall of the empty mass hanger. Let's make it heavier to see if it goes "faster." (Greater acceleration.)

1. Double the weight of the hanger by adding a 50-g mass to it. (You'll have to turn off Z-mode temporarily to allow you to put mass on the hanger.)

- Change graph colors so that you can see the new graph along with the previous one. Take your data and record it as before but in the .100-kg section of Table 1. Calculate and record the free-fall acceleration of the 100-g mass.
- Doubling the force did not seem to double the acceleration. If $a \propto F$, we must be missing something.

"The _____ of a body is directly proportional to the net force acting on it.

So if you double the force on it, its acceleration *should* _____

When you doubled the mass in this case, the acceleration _____

This is because doubling the weight also doubled the _____

This is a very special relationship that is still not clearly understood. Why should the force of gravity on a body be directly proportional to its mass (inertia)? Or vice versa? Perhaps this will be solved in your lifetime. Stay tuned!

IIIA. The roles of Newton's 2nd and 3rd Laws in identifying the forces affecting motion.

Anyone who's ridden in an elevator is familiar with the light or heavy feeling during the elevator's upward or downward acceleration. To understand the source of this feeling and why it makes us feel like our weight has changed it's important to be clear about the forces involved.

In Figure 9 we have the two opposing forces acting on our mass hanger. Are they an action-reaction pair? No! And not just because they aren't necessarily equal. Since each force must be associated with an equal and opposite reaction force, there must be some other forces involved.

Newton's 2nd Law quantifies the effect of one or more external forces acting on a body (or system.) Only forces acting on that body are considered using this law. In our free-body diagrams we use a dot to represent the object we're interested in.

Newton's 3rd Law describes the forces acting between a pair of bodies. One force acts on one body and the other (equal but oppositely directed) force acts on the other body. Since these forces act on different bodies only one of them should appear in an equation created using the 2nd Law.

Newton's 2nd Law: $\Sigma F = ma$ where ΣF is the sum of the forces on a body (or system) with mass m .

These forces may or may not be equal. They all act on one body.

Newton's 3rd Law: Body 1 exerts a force on body 2.

Body 2 exerts an equal but opposite on body 1.

The 3rd Law helps us identify all the forces involved in an interaction between bodies.

FBD's help us determine which of these forces are used in the 2nd Law: They show the external force on one body or system.

Figure 10 shows the four forces involving the mass hanger. If you were to drop the hanger it would free-fall due to the **Earth's downward gravitational force on the hanger**. The Earth would also be pulled upward by the **hanger's gravitational force on the Earth**. These forces are an action-reaction pair and are equal in magnitude as described by the 3rd Law. The 2nd Law explains why their free-fall accelerations are different – both the force on *and* the mass of the object determine its acceleration.

$$F(\text{hanger on Earth}) = -F(\text{Earth on hanger}), W_r \quad \text{A-R pair \#1}$$

The hanger doesn't free-fall because of a second force on it – the **upward force of the string on the hanger, T_r** . The reaction to this force is the downward **force of the hanger on the string**.

$$F(\text{hanger on string}) = -F(\text{string on hanger}), T_r \quad \text{A-R pair \#2}$$

These two pairs of action-reaction pairs are diagonal to each other in Figure 10. Notice that in each pair the nouns (names) just change places.

How do you decide which forces go into your FBD and Newton's 2nd Law equation?

- Decide which object you're interested in. (The hanger.)
- Use just the forces acting **on** it.

Newton's second law relates the two forces acting on the hanger, the force on the right sides of the equations above and on the right side of Figure 10.

$$T_r - W_r = m_r a$$

IIIB. Apparent Weight

Now suppose that instead of the mass hanger, **you** were clinging to the end of string. You are the dot in the figure. Gravity pulls you downward with a force W_r . The string pulls up with a force T_r .

That force, T_r , is what we call your apparent weight.

W_r is your actual weight, mg



Fig 9 - FBD

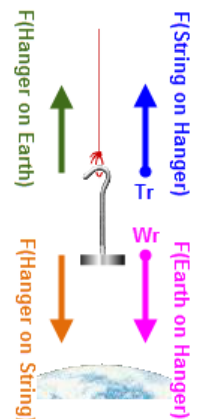


Fig. 10 – All Forces on Hanger

Your apparent weight equals the upward force on you needed to hold you at rest, move you up or down at constant speed, or accelerate you up or down. This force changes according to your motion and you can feel the change.

Hanging at the end of the string you would find that you sometimes feel heavier than usual in that you feel like you're being stretched out. Other times you'd feel lighter than usual, like you're holding up a lighter you.

The more familiar case is when you ride in an elevator. In an elevator you feel heavier than normal or lighter than normal depending on your upward or downward acceleration, respectively. If you stand on a scale in the elevator, the scale reading matches that feeling.

Let's explore this with our apparatus. To make it more vivid, imagine yourself as the right mass hanger (and any attached masses.) You're holding the string to keep from falling. You might also choose to stand on the hanger.

To make you accelerate up and down we need a hanger on the left side.

- Set up the system shown in Figure 11. You'll want a string and empty hanger on each side.

You'll want **Z-mode** for this activity. Also Recoil = 0.

Turn on Dynamic Vectors. Check (turn on) Hangers and Velocity.

These vectors get in the way of the left hanger. The column of arrows that identify the vector colors is also a toggle to show/hide the check boxes. You might want to hide them.

Add 50 grams to each hanger You're on the right. **Your mass (m_r) is 100 g!**

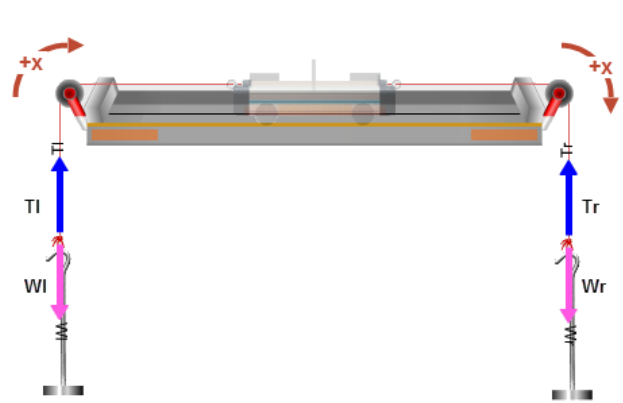


Figure 11 – Apparent Weight

- Let's look at the initial situation - hanging from the rope at rest. That is, $v_o = 0$ and constant.

$$a = 0 \quad \text{So } T_r = W_r$$

Note the length of these vectors on the right side. They're equal since $a = 0$.

- Now give the cart a good shove in either direction. Or use $V_o \rightarrow$.

- How does your apparent weight (T_r) at rest compare to T_r when moving at a constant velocity? Circle one.

$$T_r(\text{rest}) < T_r(\text{constant velocity}) \quad T_r(\text{rest}) > T_r(\text{constant velocity}) \quad T_r(\text{rest}) = T_r(\text{constant velocity})$$

From this you should conclude that your apparent weight, T_r should be your normal weight. This means that if you were hanging from the string you wouldn't feel any more stretched out moving at a constant speed than when at rest. Likewise if you were standing on the scale you wouldn't feel any more squished down by gravity than usual.

- Now try an upward acceleration. Add 100 grams to the left hanger. You should now have a total of 100 g on the right and 200 g on the left. Drag the cart to near the right end of the track. Ignore the situation when $T_r = W_r$ when the cart is being held. You want to notice what happens just when you release the carts.

- When you release the cart, what happens to your *apparent weight*, T_r ? (*increases, decreases, or remains the same.*)

Your apparent weight, T_r _____

- When you release the cart, what happens to your *actual weight*, W_r ? (Same choices.)

Your actual weight _____

What would it be like, relative to when you were riding at a constant speed, if you were hanging from the string or standing on the hanger? (*stretched or compressed.*)

- If you were hanging from the string you would feel _____

- If you were standing on the hanger you would feel _____

7. Now try a downward acceleration. Adjust the masses so that the right side is still 100 g and the left side is an empty 50-g hanger. Drag the cart to near the left end of the track.

7a. When you release the cart, what happens to your *apparent weight*, T_r ? (*increases, decreases, or remains the same.*)

Your apparent weight, T_r _____

7b. When you release the cart, what happens to your *actual weight*, W_r ? (Same choices.)

Your actual weight _____

What would it be like, relative to when you were riding at a constant speed, if you were hanging from the string or standing on the hanger? (*less stretched or less compressed.*)

7c. If you were hanging from the string you would feel _____

7d. If you were standing on the hanger you would feel _____

8. When you accelerate upward your apparent weight _____

9. When you accelerate downward your apparent weight _____


10. When you are at rest or moving at a constant speed your apparent weight equals _____

IV. Kinetic Friction

And finally, let's have a quick look at kinetic friction. For this study we'll just be working with the **normal** cart. The only force affecting its motion will be kinetic friction. So click [Reset All] to remove all the masses and hangers.

So far the only friction force we've encountered is the one supplied by the cart brake. It's much too strong a force for our purposes. Instead we'll use a friction pad similar to the brake. But this one is adjustable. In Figure 12 you see a snapshot of the cart traveling to the right at velocity v_o . A friction force, the net force, acts to the left, thus slowing the cart down.

In Figure 13 you see the wheels/friction pad control. When "wheels" is selected (Fig. 13a) the V_o controls are active. By selecting "friction pad" (Fig. 13b) the controls change to allow you to adjust μ_k , and μ_s . (They can't both be selected at once. Each is shown in its selected mode.) We'll use only kinetic friction which is controlled by the μ_k stepper. We'll start with it set just as it is in the figure. After one trial you'll try to determine an unknown kinetic friction coefficient.

1. Click the friction pad radio button to turn on the friction controls. Set the friction controls as shown in Figure 13b.
2. Turn on the ruler. Move it above the dynamic vectors display.
3. Move the cart to $x = 10.0$ cm. (This is the position of the cart mast.)
4. Turn on the dynamic vectors:  Check (turn on) Velocity, Net Force, and Friction.
5. Click "wheels" and set V_o to 200 cm/s. Then switch back to "friction pad."

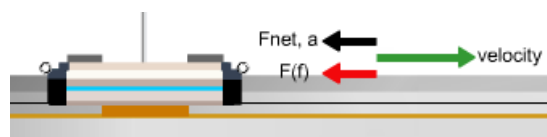
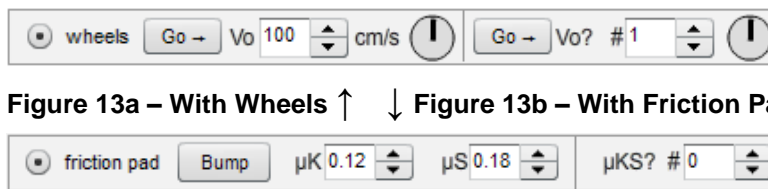


Figure 12 – Friction Pad



6. Click Go→

The cart should launch to the right and slow to a stop before reaching the right bumper. If not, retry the preceding instructions.

Repeat the preceding step as needed to answer the following.

7. Clearly the cart slows down. What about the friction vector, F_f , tells you why it slows down.

8. What about the velocity vector tells you that it does slow down.

The cart slows down due to the friction force acting on it. From Newton's second law we know

$$\begin{aligned} \Sigma F &= ma \\ F_f &= ma \\ F_f &= -\mu_k F_N = -\mu_k mg \\ -\mu_k mg &= ma \\ \mu_k &= -a/g \end{aligned} \tag{2}$$

So if we knew a , we could divide by g to determine μ_k .

How can we find the acceleration, a ? If we launch the cart along the track, letting it come to a halt we know

$$v_o = 2.00 \text{ m/s}$$

$$v_f = 0.00 \text{ m/s}$$

Δx can be found with the ruler

a can be found from a single kinematics equation. You figure that part out.

9. Got it? Take the data you need and record it in Table 2. If your value for μ_k is not close to .12, then you've done something wrong with your technique or your calculations. You should get a negative value for the acceleration.

Table 2 Determination of known $\mu_k = .12$ $g = 9.80 \text{ m/s}^2$	Show calculations below for a and μ_k
$v_o = \underline{\hspace{2cm}} \text{ m/s}$	
$x_1 = \underline{\hspace{2cm}} \text{ m}$	
$x_2 = \underline{\hspace{2cm}} \text{ m}$	
$\Delta x = \underline{\hspace{2cm}} \text{ m}$	
$a = \underline{\hspace{2cm}} \text{ m/s}^2$	
$\mu_{k(\text{experimental})} = \underline{\hspace{2cm}}$ (no units)	

10. Let's try an unknown friction coefficient. Change the $\mu_{ks?}$ value to 2 using the numeric stepper. You'll quickly find that your 2.00 m/s is not a good choice this time. You can change it to whatever you like. But letting the cart go most of the way along the track will give better results than a short run. Note also that the new μ_k should be much smaller than the previous value.

Table 3 Determination of known $\mu_{ks?}$ $g = 9.80 \text{ m/s}^2$	Show calculations below for a and μ_k
$v_o = \underline{\hspace{2cm}} \text{ m/s}$	
$x_1 = \underline{\hspace{2cm}} \text{ m}$	
$x_2 = \underline{\hspace{2cm}} \text{ m}$	
$\Delta x = \underline{\hspace{2cm}} \text{ m}$	
$a = \underline{\hspace{2cm}} \text{ m/s}^2$	
$\mu_{k(\text{experimental})} = \underline{\hspace{2cm}}$ (no units)	

Blank Page