

Name _____ School _____ Date _____

The Force Table – Vector Addition and Resolution

“Vectors? I don't have any vectors, I'm just a kid.” – From Flight of the Navigator

PURPOSE

- To observe how forces acting on an object add to produce a net, resultant force
- To see the relationship between the equilibrant force relates to the resultant force
- To develop skills with graphical addition of vectors and vector components
- To develop skills with analytical addition of vectors and vector components

EXPLORE THE FORCE TABLE APPARATUS; THEORY

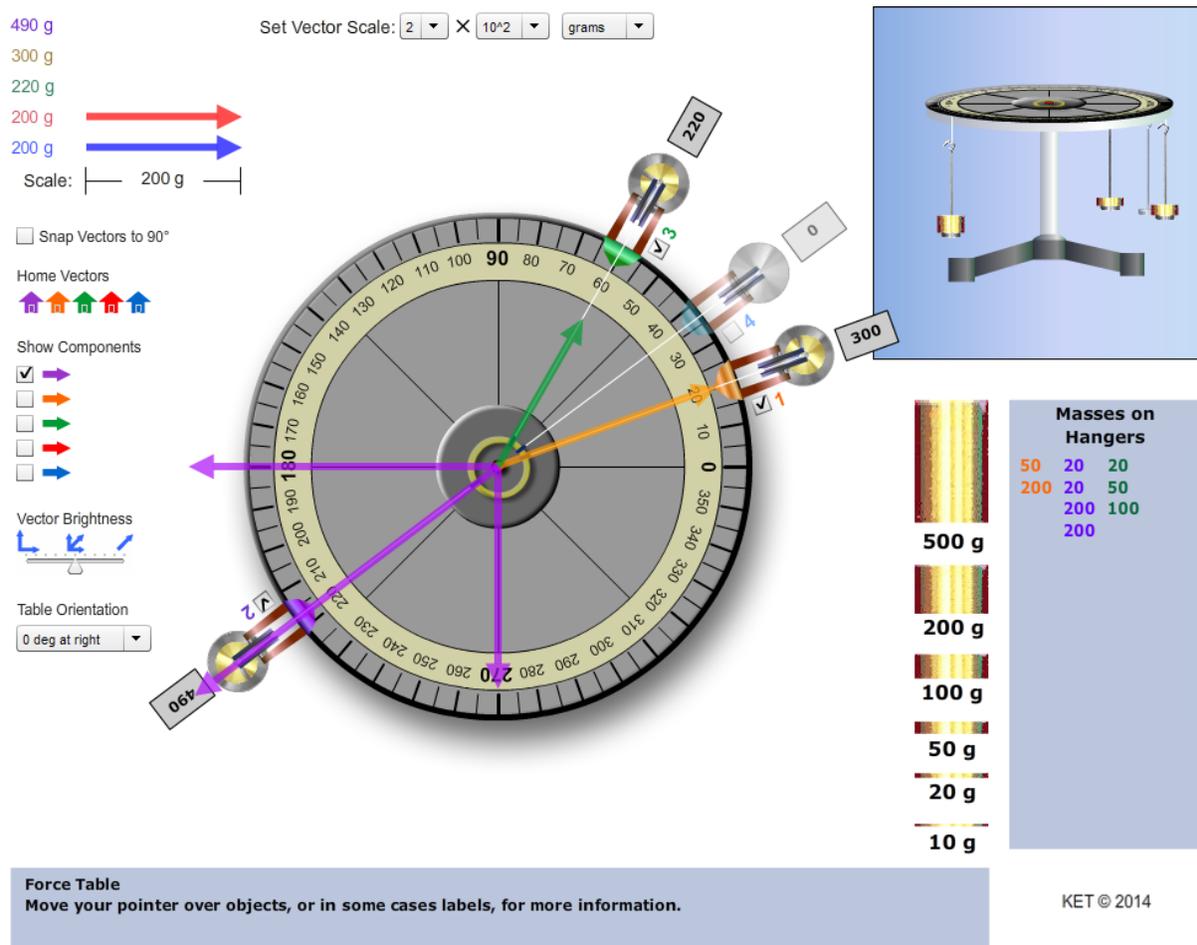


Figure 1 – The Force Table Apparatus

Important Note: For each direction answer enter an angle between 0° and 360° with respect to the force table.

Working with vectors graphically is somewhat imprecise. You should expect to see lower precision in this lab. But working with vectors graphically will give you a better understanding of vector addition and vector components. You can improve your precision by using the Zoom features of the apparatus.

PROCEDURE

I. Addition of Two Dimensional Vectors

In this part you'll add two forces to find their resultant using *experimental addition*, *graphical addition*, and *analytical addition*. The two forces you'll work with are:

$$F_2 = .300 \text{ g N at } \theta_2 = 320^\circ \quad (\text{the angles } \theta_2 \text{ and } \theta_4 \text{ are good choices for student variables})$$

$$F_4 = .180 \text{ g N at } \theta_4 = 60^\circ$$

There are two things that we should clarify about these two statements. We'll refer to Figure 1 in the following.

- The force subscripts on forces and angles (F_2 , θ_2) refer to the hanger numbers. For example, in Figure 1, $\theta_1 = 20^\circ$
- The notation for forces in this lab is a bit unusual. From the "Masses on Hangers" table we know that hanger #1 has a 50 g, and a 200 g mass on it. The hanger's mass is 50 g, so the total, 300 g, is shown in the box beside the hanger. Be we want to record forces in newtons. From $W = mg$, we can easily calculate the weight of a 300-g mass.
 $W = .300 \text{ kg} \times 9.8 \text{ N/kg} = 2.94 \text{ N}$
 But there's a much more convenient way of handling this. We can abbreviate this calculation to the simpler
 $W = .300 \text{ g N}$

A. Experimental Addition; the Equilibrant

By *experimental addition* we mean that we will actually apply the two forces to an object and measure their total, resultant effect. We'll do that by first finding the equilibrant, E , the force that exactly balances them. When this equilibrium is achieved the ring will be centered. The resultant, R , is the single force that exactly balances the equilibrant. That is, either F_2 and F_4 , or their resultant R can be used to balance the equilibrant.

Note: When adjusting the angle of a pulley to a prescribed angle, pay no attention to the string. Drag the pulley until the color-coded pointer is at the desired setting. Another way that works well is to disable all the hangers while adjusting the angles. When you do this, the ring is automatically centered so the strings can be used to help adjust the angle.

1. Enable pulleys 2 and 4 and disable pulleys 1 and 3 using their check boxes. A disabled pulley is greyed out. You can drag it anywhere you like since any masses on it are inactive.
2. Drag pulleys 2 and 4 to their assigned angles θ_2 and θ_4 . Use the purple and blue pointers of the pulley systems, not the strings, to set the angles. You should zoom in to set the angles more precisely.
3. Add masses to hangers 2 and 4 to produce forces F_2 and F_4 .
4. Enable pulley 3.
5. Using pulley 3, experimentally determine the equilibrant, E , to just balance (cancel) F_2 and F_4 . Do this by adjusting the mass on the hanger and the angle until the yellow ring is approximately centered on the central pin. You can add and remove masses to home in on it. You add masses by dragging and dropping them on a hanger. You remove them using the Mass Total/Mass Removal tool. This tool displays the total mass on the hanger, including the hanger's mass. Clicking on the tool removes the top mass on the hanger.

750

MT/MR
Tool

Experimental Equilibrant, E : _____ g N, _____ $^\circ$

6. From your value of E , what should be the resultant of F_2 and F_4 ? (Same force, opposite direction.)

Predicted Resultant, R : _____ g N, _____ $^\circ$

7. Disable pulleys 2 and 4 and enable pulley 1. Experimentally determine the resultant by adjusting the mass on pulley 1 and its angle until it balances the equilibrant. That is, the ring should not move substantially when you change between enabling F_2 and F_4 , and enabling just F_1 .

Experimental Resultant, R : _____ g N, _____ $^\circ$

B. Graphical Addition

With *graphical addition* you will create a scaled vector arrow to represent each force. We add vector arrows by connecting them together tail to head in any order. Their sum is found by drawing a vector from the tail of the first to the head of the last. Using the default 2×10^2 g vector scale, create vector arrows (± 3 grams) for F_2 , F_4 . For example, drag the purple vector by its body and drop it when its tail (the square end) is near the central pin. It should snap in place.

You now want to adjust its direction and length to correspond to direction and magnitude of F_2 . It's hard to do both of these at the same time. That's where the **Resize Only** and **Rotate Only** tools come into play. They let you first adjust the direction and then adjust the length. Let's do F_2 .

Zoom in. Drag the head (tip) of the vector arrow in the assigned direction force F_2 . That is, θ_2 . Zoom out. Click the Resize Only check box. Its direction is now fixed until you uncheck that box. You can now drag the head of the arrow and adjust just its magnitude without changing its direction. The current magnitude of F_2 is displayed at the top of the screen next to the home location of that purple vector. You need to adjust its length to 310 ± 3 g. Repeat for F_4 using the blue arrow.

The resultant, R , is the vector sum of F_2 and F_4 . Add F_2 and F_4 graphically by dragging the body of F_4 until its tail is over the tip of F_2 and releasing it. Form the resultant, R , by creating an orange vector, F_1 , from the tail of the first vector, F_2 , to the head of the last vector, F_4 . (You can actually connect F_2 and F_4 in either order.) You can read the magnitude and direction of R directly from the length and direction of F_1 . You'll likely find some disagreement between these results and your results from part A. This is because both methods are somewhat imprecise.

- Graphical Resultant, R : _____ g N, _____ °

The equilibrant, E , should be the same magnitude as R , but in the opposite direction. Produce E with the green vector arrow. It should be attached to the central pin and in the direction of the force F_3 .

- Graphical Equilibrant, E : _____ g N, _____ °
- Draw each of the four vector arrows on Figure 2. Vectors F_2 and F_4 should be shown added in their tail to head arrangement. The E and R vectors should be shown radiating out from the central pin. Label each vector with its force value in g N units.
- Take a Screenshot of the force table showing your four force vectors. Make it large enough to include the MT/MR text boxes displaying the mass values. Disable pulley 1 so as to show the system in equilibrium. Save the figure locally as "FTable_2.png", print it out, and paste it in the space provided.

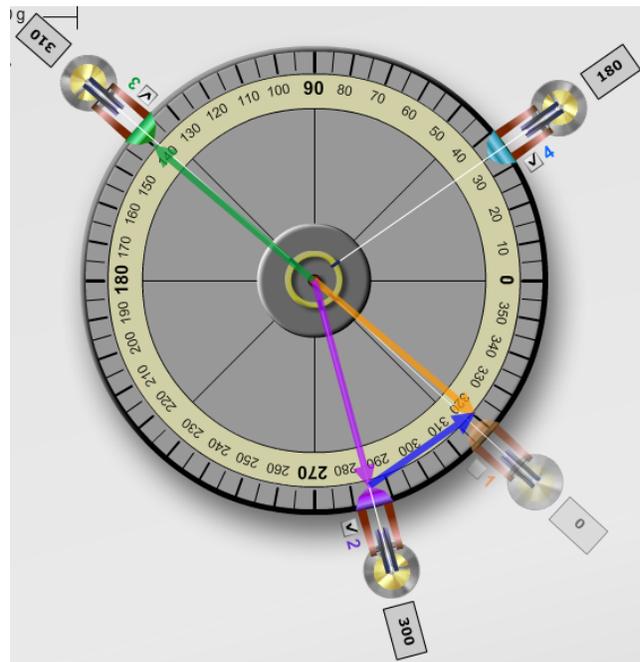


Figure 2: Graphical Addition; Equilibrant 

- Describe what we mean by the terms resultant and equilibrant in relation to the forces acting in this experiment?

6. From your figures, which two forces, when added would equal zero?

Circle two F_2 F_4 E R

7. Show this graphical addition in the space to the right. You'll want to offset them a bit since they would otherwise be on top of one another.
8. Create the same arrangement somewhere on the screen on your apparatus. Take a Screenshot, save it locally as "FTable_3.png", print it out, and paste it in the space provided.
9. What three vectors, when added would equal zero?
- Circle three F_2 F_4 E R
10. Show this graphical addition in the space to the right.
11. Create the same arrangement somewhere on the screen on your apparatus. Take a Screenshot, save it locally as "FTable_4.png", print it out, and paste it in the space provided.

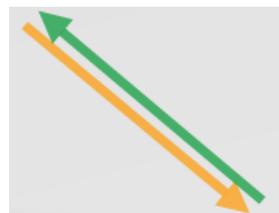


Figure 3: Two Forces Adding to Zero



Figure 4: Three Forces Adding to Zero

12. Vector E should appear in both Figure 3 and Figure 4. Why?

C. Analytical addition with components

You've found experimentally and graphically how to add the forces F_2 and F_4 to produce the resultant, R . Hopefully you found that these two methods make it very clear to you what is meant by the addition of vectors. But you also found that both methods are pretty imprecise – sort of the stone tools version of vector addition. We can get much better results using trigonometry.

You've just verified that the resultant effect of two (or more) vectors can be found by attaching them together tail to head and drawing a new vector from the tail of the first to the head of the last. That single new vector is equivalent to the two original vectors acting together. So the one achieves the same result as the original two. The reverse is also true. We can simplify the process of addition of vectors if we replace each vector with a pair of vectors whose sum equals the original vector. At least if we do it strategically.

- Put all four vectors back at the center of the force table with their tails snapped to the central pin. Click the check box beside the purple arrow under "Show Components." Zoom in for a better look. The two new purple vectors are the x and y-components of the purple vector, F_2 . We would call them F_{2x} and F_{2y} .
- Drag the x-component, F_{2x} and add it to the F_{2y} . That is, connect its tail to the head of F_{2y} . Clearly they add up to F_2 . But just to be sure, drag F_{2x} back to the center and add F_{2y} to it. Same result.

$$\text{So } \mathbf{F}_2 = \mathbf{F}_{2x} + \mathbf{F}_{2y}. \quad \text{A}$$

Note that this is all vector addition. We're using bold text for our vector names to emphasize that this is not scalar addition, which doesn't take direction into account. F_2 equals the **vector sum** of F_{2x} and F_{2y} because when we connect the components together tail to head, the vector from the tail of the first to the head of the last is F_2 .

So, we can use F_2 and $F_{2x} + F_{2y}$ interchangeably. That's the strategic part.

- Turn on the blue components.

4. We'll dim the main vectors. Drag the large blue dragger on the Vector Brightness tool almost all the way to the left. Only the components will remain bright. Leaving one of them, say F_{2x} where it is, add the other three components to it in any order you like. This might be a good time to Hide the Table. There's a button at the top. Feel free to hide and show the force table as needed.
5. Notice where the head of the last component ends up. Notice how the four components add up to R ! Try another order of addition. The order doesn't matter. So we can say,

$$\mathbf{R} = \mathbf{F}_1 = \mathbf{F}_{2x} + \mathbf{F}_{2y} + \mathbf{F}_{4x} + \mathbf{F}_{4y} \quad \text{in any order.}$$

Remember, this is vector addition, not scalar addition. So we're still having to connect them together graphically to find the resultant. We're still using stone tools.

6. Turn the components for F_1 . You now have three sets of components.
7. Drag all the y-components out of the way.
8. Add F_{2x} and F_{4x} together.
9. How do these two vectors relate to F_{1x} that is, R_x ?

10. Repeat with the y-components. What similar statement can you make about the y-components?

11. Finally, how is R related to R_x and R_y ?

To summarize,

$$R_x = F_{2x} + F_{4x} \text{ and } R_y = F_{2y} + F_{4y} \text{ and } \mathbf{R} = R_x + R_y$$

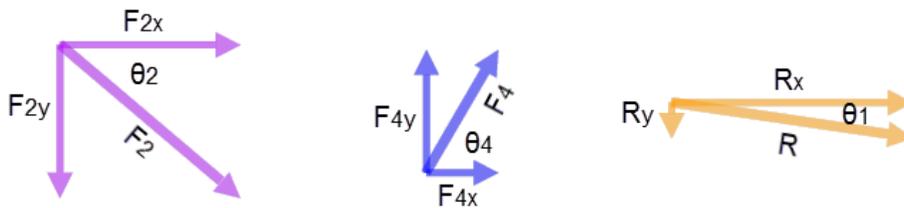


Figure 5: Vector Components

We can now leave our stone tools behind and take advantage of this new formulation by using trigonometric functions and the Pythagorean Theorem.

Here's our task. You were previously asked to find the resultant, R of F_2 and F_4 graphically. You now want to find the same result without the using the imprecise graphical methods.

Knowing F_2 and θ_2 we can calculate F_{2x} and F_{2y} analytically as follows.

$$F_{2x} = F_2 \cos(\theta_2) \tag{1}$$

$$F_{2y} = F_2 \sin(\theta_2) \tag{2}$$

We can do the same for F_4 . We can then find R_x and R_y using

$$R_x = F_{2x} + F_{4x} \tag{3}$$

$$R_y = F_{2y} + F_{4y} \tag{4}$$

$$\mathbf{R} = R_x + R_y \tag{5}$$

There's one slight problem with Equation 5. Like Equations 3, and 4, it's a vector equation, but in Equations 3, and 4, the vectors are collinear, so they can be added with signs indicating direction. But since vectors \mathbf{R}_x and \mathbf{R}_y are perpendicular, we have to use the Pythagorean Theorem instead. So we can find the magnitude and direction of the resultant, \mathbf{R} with the magnitudes of \mathbf{R} 's components.

$$R^2 = R_x^2 + R_y^2 \tag{6}$$

$$\tan(\theta) = R_y/R_x \tag{7}$$

12. You've found experimentally and graphically how to add the forces \mathbf{F}_2 and \mathbf{F}_4 to produce the resultant, \mathbf{R} . Now let's try analytical addition. Using the table provided, find the components of \mathbf{F}_2 and \mathbf{F}_4 and add them to find the components of \mathbf{R} . Use these components of \mathbf{R} to determine the magnitude and direction of \mathbf{R} . Note that one of the four components will have a negative sign. The components now displayed on the force table should make it clear why.
13. Show **all** your calculations leading to your value for \mathbf{R} below. Remember, a vector has both a magnitude and a direction. A summary of the steps is provided to get you started.

x-Components		y-Components	
$F_{2x} =$	g N	$F_{2y} =$	g N
$F_{4x} =$	g N	$F_{4y} =$	g N
$R_x =$	g N	$R_y =$	g N
$\mathbf{R} =$ g N, ° (State your angle between 0 and 360°.)			

$$F_{2x} = F_2 \cos(\theta_2) = .300 \text{ g N } \cos(\theta_2)$$

$$F_{2y} = F_2 \sin(\theta_4) = .300 \text{ g N } \sin(\theta_4)$$

$$R_x = F_{2x} + F_{4x}$$

$$R_y = F_{2y} + F_{4y}$$

$$R^2 = R_x^2 + R_y^2$$

$$\tan(\theta) = R_y/R_x$$

II. SIMULATION OF A SLACKWIRE PROBLEM.

Let's model a realistic system similar to what you might find in your homework. Figure 6 shows a crude figure of slackwire walker, Elvira, making her way across the wire. She weighs 450 N. (About 100 lbs.) At a certain instant the two sides of the rope are at the angles shown. Only friction allows her to stay in place. The gravitational force is acting to pull her down the steeper 'hill.' If she was on a unicycle she'd tend to roll to the center. It's complicated.

When friction is holding her in place the single rope acts like two separate sections of rope in this situation with different tension forces on either side of her. To understand this it helps to imagine her at the extreme left where the left section of rope is almost vertical and the right one is much less steep. In this case \mathbf{T}_3 is providing almost all of the vertical support, while \mathbf{T}_1 pulls her a little to the right. It helps to just try it. Attach a string between two objects in the room. Leave a little slack in it. Now pull down at various points. You'll feel the big frictional tug on the more vertical side and less from the more horizontal side.

We want to explore this by letting her move along the rope.

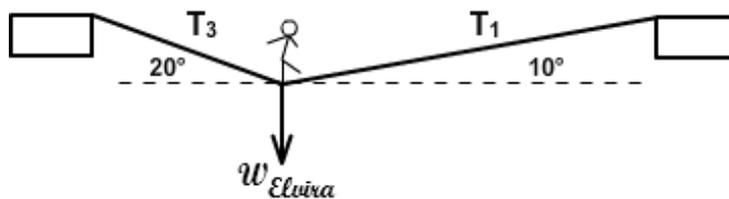


Figure 6: Elvira Off-center on the Slackwire

A. Experimental Determination of T_1 and T_3

1. Preliminary prediction: Which tension do you think is greater, T_1 or T_3 ? Circle one.

First send each of your vectors “home” by clicking on each of their little houses. Then remove all the masses from your four pulleys by activating all of them using their click boxes and then clicking in the total mass boxes beside each hanger until they read 50.

Elvira weighs _____ N.

We'll let one gram represent 1 N on our force table and set our vector scale to 4×10^2 N. (Note the label to the left of each vector.) We'll picture our force table as if it were in a vertical plane with 270° downward and 90° upward. We'll use pulleys 1, 3, and 2 to provide our two tensions, T_1 and T_3 , and the weight of Elvira respectively.

Disable all pulleys and set all the angles to match Figure 6. Use Zoom.

Turn pulleys 1, 3, and 2 back on.

2. Prediction: Since $\theta_3 = 2 \times \theta_1$, do you think T_3 will be about twice T_1 ? _____
3. Set Elvira's weight to the value you were assigned. If you're assigned a weight of 450 N, use 450 g including the mass of the hanger. So you'd add 400 g.
4. Adjust the masses on each pulley until you achieve equilibrium. It's best to alternate adding one mass to each side in turn until you get close to equilibrium.
5. $T_1 =$ _____ N at 10°
6. $T_3 =$ _____ N at 160°

How'd that prediction go (#2)? If trig functions were linear we wouldn't need them.

7. Write a statement about the relationship between the steepness of the rope and the tension in that rope for this vertical arrangement.
-

B. Graphical Check of our Results

- Using the vector scale of 4×10^2 N, create vector arrows for each force, T_3 , T_1 , and W .

Don't forget to use the Resize Only tool after you get the angles set.

- Take a Screenshot, save it locally as "FTable_7.png", print it out, and paste it in the space provided.
- Draw your three vectors on Figure 7.
- How can we graphically check to see if our values for T_1 and T_3 are reasonably correct? How are T_1 , T_3 , and W related? What would happen if any one of them suddenly went away? Elvira would no longer be in _____.

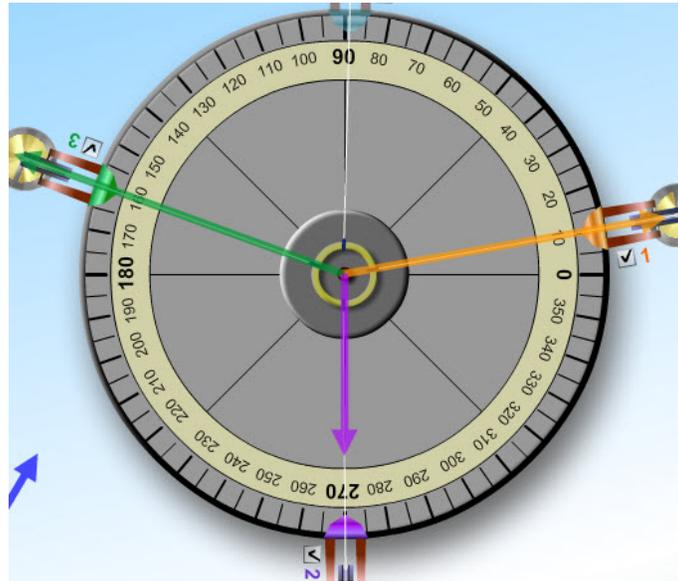


Figure 7: Elvira – Asymmetrical Vectors 

Thus the three vectors are in equilibrium and must add to equal zero! What would that look like? The sum, resultant, of three vectors is a vector from the tail of the first to the head of the last. If they add up to zero, then the resultant's magnitude would be zero which means that the tip of the final vector would lie at the tail of the first vector.

Try it in with your apparatus. Leave T_1 where it is, then drag T_3 's tail to T_1 's head. Then drag W 's tail to the head of T_3 .

- What about your new figure says (approximately) that the three forces are in equilibrium?

- Draw your new figure with the three vectors added together on Figure 8.
- Take a Screenshot, save it locally as "FTable_8.png", print it out, and paste it in the space provided.

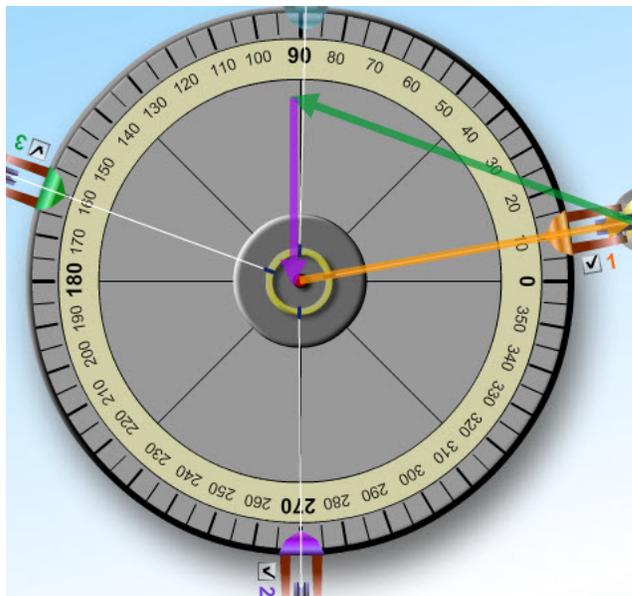


Figure 8: Graphical Addition - Asymmetrical 

C. Analytical Check of Your Results

If our three vectors add up to zero, then what about their components?

1. When you add up the x-components of all three vectors the sum should be _____
2. When you add up the y-components of all three vectors the sum should be _____
3. Test your predictions using the following table. Don't forget the direction signs!

x-Components	y-Components
$F_{1x} = \underline{\hspace{2cm}} \text{ N}$	$F_{1y} = \underline{\hspace{2cm}} \text{ N}$
$F_{3x} = \underline{\hspace{2cm}} \text{ N}$	$F_{3y} = \underline{\hspace{2cm}} \text{ N}$
$W_x = \underline{\hspace{2cm}} \text{ N}$	$W_y = \underline{\hspace{2cm}} \text{ N}$
$\Sigma F_x = \underline{\hspace{2cm}} \text{ N}$	$\Sigma F_y = \underline{\hspace{2cm}} \text{ N}$

4. Show your calculations of the eight values in the table in the space provided below.

Before we continue... Why all the tension?

Why does the tension on each side have to be so much larger than the weight actually being supported? All the extra tension is being supplied by the x-components. Then why not just get rid of it? You'd have to move the supports right next to each other to make both ropes vertical. That would be pretty boring and frankly nobody would pay to see such an act, even if they tried calling it "Xtreme Urban Slackwire."

Similarly, with traffic lights, a huge amount of tension is required to support a fairly light traffic light. The simpler solution of a pair of poles in the middle of the intersection wouldn't go over much better than Xtreme Urban Slackwire.

Next time you see poles or towers supporting large electrical wires look for places where the wire has to change direction. (South to East for example.) The support structures in straight stretches (in-line) don't have to be really sturdy since they have horizontal forces pulling equally in opposite directions. Thus they just have to support the weight of the wire. When the wires have to change directions the poles at the corners have to provide these horizontal forces. Thus they're much sturdier and larger to give them a wider base. They often have guy wires to the ground to help provide these forces. To make things more difficult the guy wires will be usually be very steep so they have to have a lot of extra tension in them to supply the horizontal force components.

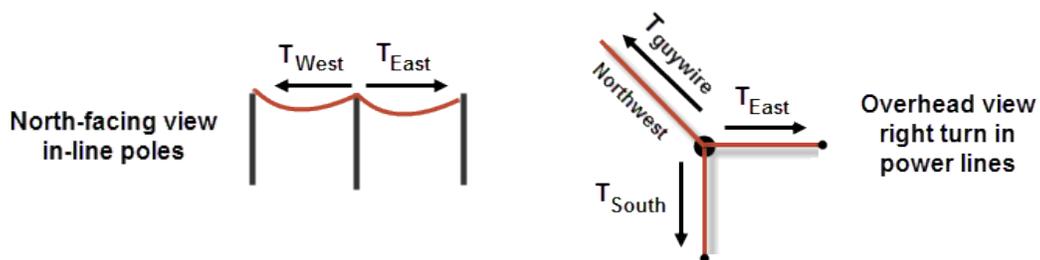


Figure 9: Power Lines – In Line and at Corners

III. SIMULATION OF A SYMMETRICAL SLACKWIRE PROBLEM.

In Figure 10, Elvira has reached the center of the wire. This is where she would be if she rode a unicycle and just let it take her to the “bottom.” The angle values are just guesses. They’d be between the 10° and 20° we had before, but the actual value would depend on the length of the wire and its elastic properties.

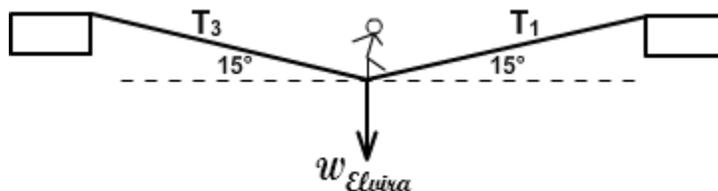


Figure 10: Elvira at the Center of the Slackwire

Without changing the masses used in part II, adjust both angles to 15° .

1. What does the **symmetry** of the figure suggest about how the tensions T_1 , and T_3 should compare?

2. Similarly what can you say about comparative values of the x-components T_{1x} and T_{3x} ? (Ex. Maybe $T_{1x} = 2 \times T_{3x}$?)

3. What can you say about comparative values of the y-components T_{1y} and T_{3y} ?

4. Knowing that the weight being supported is 450 N, what can you say about actual values of the y-components T_{1y} and T_{3y} ?

5. $T_{1y} = T_{3y} =$ _____ N

You can now easily calculate T_1 and hence T_3 .

6. $T_1 = T_3 =$ _____ N at 15°

Show the calculation of T_1 below.

7. Change each **T** to as close as you can get to this amount. Does this produce equilibrium? _____
8. With your apparatus, create the two vector arrows to match this amount - one for T_1 and one for T_3 . Add $T_1 + T_3 + W$ graphically. Draw or paste a copy of this graphical addition below.

9. Create the two vector arrows to match this amount - one for T_1 and one for T_3 . Add $T_1 + T_3 + W$ graphically. Draw or paste a copy of this graphical addition in Figure 11.
10. Take a Screenshot, save it locally as "FTable_11.png", print it out, and paste it in the space provided.

You'll notice that this figure doesn't differ much from the previous one. The graphical tool we're using is not very precise. The same goes for "the real world." Measuring the tension in a heavy electrical cable or bridge support cable is very difficult. One good method involves whacking it with a hammer and listening for the note it plays!

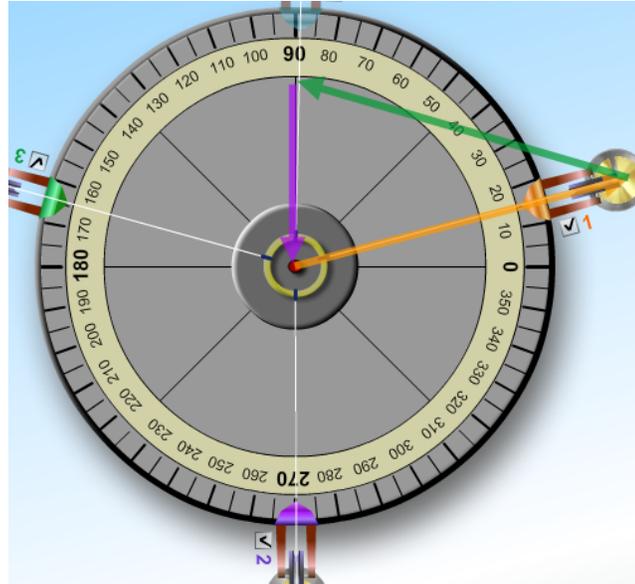


Figure 11: Graphical Addition – Symmetrical

IV. VECTOR SUBTRACTION

Here's the scenario. We have a three-person kinder, gentler tug-o-war. The goal is to reach consensus, stalemate. Two of our contestants are already at work.

$$\mathbf{Darryl}_1 = 800 \text{ N at } 0^\circ$$

$$\mathbf{Darryl}_2 = 650 \text{ N at } 240^\circ$$

The question is - how hard, and in what direction, must \mathbf{Larry}_3 pull to achieve equilibrium?

1. As before, empty all the hangers, and then set up pulleys 1 and 2 to represent these forces using 1 gram/1 newton.
2. Send all the vector arrows home to get a clean slate. Then create orange and purple vectors to match using the $4 \times 10^2 \text{ N}$ for your vector scale. Attach them to the central pin.

One method of solving the problem is to add the \mathbf{Darryl} forces to find the resultant. \mathbf{Larry} 's force would be the equilibrant in the other direction. Another way is to add the two \mathbf{Darryl} forces and then draw a third force, \mathbf{Larry} , to complete the triangle which would leave a resultant of zero.

The following vector equation describes that method.

$$\Sigma \mathbf{F} = \mathbf{Darryl}_1 + \mathbf{Darryl}_2 + \mathbf{Larry}_3 = 0$$

This is a vector equation. It means that you'll get a resultant of zero if you connect the three vectors together tail to head. To find the \mathbf{Larry} vector we need to subtract the two \mathbf{Darryl} vectors from both sides. We know how to add vectors but how do we subtract them?

With **scalar math** it would look like this:

$$\Sigma \text{Worth} = \text{Darryl}_1\$ + \text{Darryl}_2\$ + \text{Larry}_3\$ = 0 \quad (\text{Yes, that's net worth})$$

$$\text{Larry}_3\$ = -\text{Darryl}_1\$ - \text{Darryl}_2\$$$

If $\text{Darryl}_1\$ = \800 and $\text{Darryl}_2 = \$650$, they we'd get

$$\text{Larry}_3\$ = -\$800 - \$650 \quad (\text{Note that we're adding negatives here.})$$

$$\text{Larry}_3\$ = -\$1450$$

Negative dollars don't exist but we would interpret this as something like a debt. That is to make the three brothers have zero net worth, Larry₃ needs to be \$1450 in debt.

With vectors it works the same way but we interpret the negatives signs as indications of direction. A pull of -50 N to the left means a pull of 50 N to the right.

$$\Sigma \mathbf{F} = \mathbf{Darryl}_1 + \mathbf{Darryl}_2 + \mathbf{Larry}_3 = 0$$

$$\mathbf{Larry}_3 = -\mathbf{Darryl}_1 - \mathbf{Darryl}_2$$

$$\mathbf{Larry}_3 = (-\mathbf{Darryl}_1) + (-\mathbf{Darryl}_2)$$

So to find **Larry**₃ we need to create the two negative **Darryl** vectors and add them.

This means to draw the vector **(-Darryl**₁) and **(-Darryl**₂) which are the opposites of **Darryl**₁ and **Darryl**₂ and add them. That is, we can subtract vectors by adding their negatives.

So if

$$\mathbf{Darryl}_1 = 800 \text{ N at } 0^\circ$$

$$\mathbf{Darryl}_2 = 650 \text{ N at } 240^\circ$$

then the negatives of these are vectors of the same lengths but in the opposite directions. Thus,

$$-\mathbf{Darryl}_1 = 800 \text{ N at } 180^\circ$$

$$-\mathbf{Darryl}_2 = 650 \text{ N at } 60^\circ$$

3. Ruining the hard work you just did, create these two **-Darryl** vector arrows. (Don't change the mass hangers. Just the vectors.) You'll do this by just reversing the directions of both the vector arrows you initially created.

Leaving the **-Darryl**₁ vector pointing at 180°, add the **-Darryl**₂ vector in the usual tail to head fashion.

Larry₃ is the sum of these two. Create the green **Larry**₃ vector from the tail of **-Darryl**₁ to the head of **-Darryl**₂.

Draw these three vectors on Figure 12.

4. Take a Screenshot, save it locally as "FTable_12.png", print it out, and paste it in the space provided.

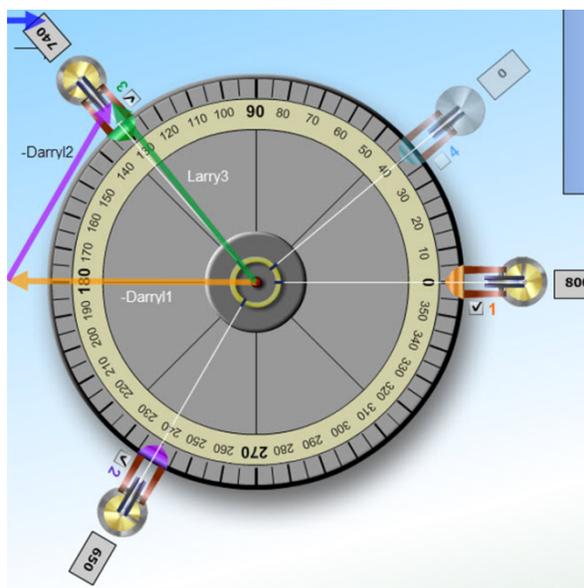


Figure 12: Larry and 2 Darryls

5. \mathbf{Larry}_3 (graphical) = _____ N _____° (from the length and direction of your green, **Larry**₃ vector)

Move pulley 3 to the position indicated by the direction of **Larry**₃. You'll want to temporarily turn off the hangers to set the angle correctly.

Place the necessary mass on hanger three to produce the **Larry**₃ force.

6. \mathbf{Larry}_3 (experimental) = _____ N _____° (from the mass on hanger 3 and the location of the pulley)

Ta Da! I hope this has made vectors as little bit less mystifying.