14010 Force Table
Teacher Instructions

Suggestions:
- If desired, paper clips can be used as partial masses (Example- if the mass required is 2.5 washers, the 0.5 washer can be represented with washers to make true equilibrium). A washer weighs approximately 6 g, and a standard paper clip weighs approximately 0.5 g. Students are encouraged to weigh both the washers and the paper clips to determine the exact ratio.
- If desired, hanging masses can be used rather than washers. Every part of the procedure is written with a 20 washer limit, but hanging masses can be substituted if necessary.
- If the pulleys are attached too tightly, then they can damage the table top. Students should be instructed to only tighten the pulleys as much as necessary to keep the pulley from moving, and no more than that. Padding (such as double-sided tape or foam) can be added to the underside of the pulleys to help prevent damage if desired.
- Students should make sure that the thread does not get stuck on the ring, as this can prevent the apparatus from working properly. Make sure students keep the thread out of any divots in the ring.

Brief description of procedure

This procedure allows students to investigate the equilibrium of forces. The procedure begins with students using an equal number of washers at equal angles to each other, and continually increase the difficulty of determining equilibrium, until students have to calculate exact mass and location for multiple pulleys in order to achieve equilibrium.

Because of the knowledge of mathematics necessary for this procedure, it is recommended for students who have taken trigonometry (usually, grades 10-12). Younger grades can use the Force Table; however, modifications to the procedure would be necessary for younger students to be able to use it effectively. In the younger grades, this apparatus may be better served as a demonstration or student exploration with simpler situations, rather than the procedure given.

Other optional demonstrations

An optional addition (which is brought up in the assessment section) is to include a demonstration or additional procedure about four pulleys, as the current procedure only utilizes three pulleys. Students are asked to calculate the necessary vectors for equilibrium in a four-pulley system during assessment questions 4-6.

Answers:

Procedure Answers:

Q1. Predict what would happen if six washers were placed on each hanger.

Answers may vary from student to student.

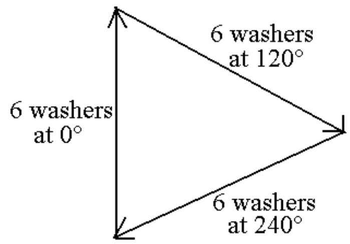
Q2. Where is the center post in relation to the ring?

The center post is in the middle of the ring. If the setup is at equilibrium, with no force pulling one way or the other, the center post will be in the exact center of the ring.

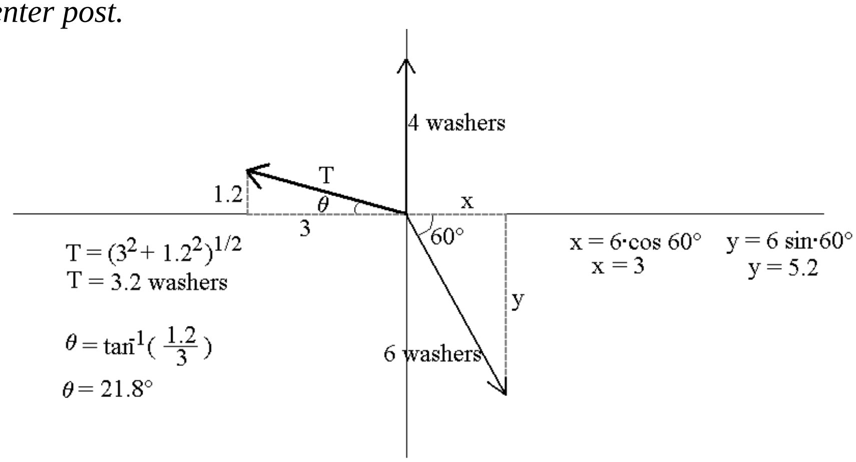
Q3. Was your prediction correct?

Answers will vary from student to student, but will depend upon their answer to Q1.

Q4. Using the head-to-tail method, prove the forces are in equilibrium.



Q5. Predict where the third pulley should be, and how many washers need to be on the hanger for the ring to be centered around the center post.

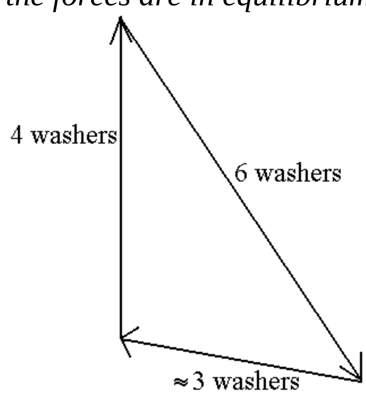


The pulley must be placed at 291.8° (approximately 292°), and there must be 3.2 washers (approximately 3 washers).

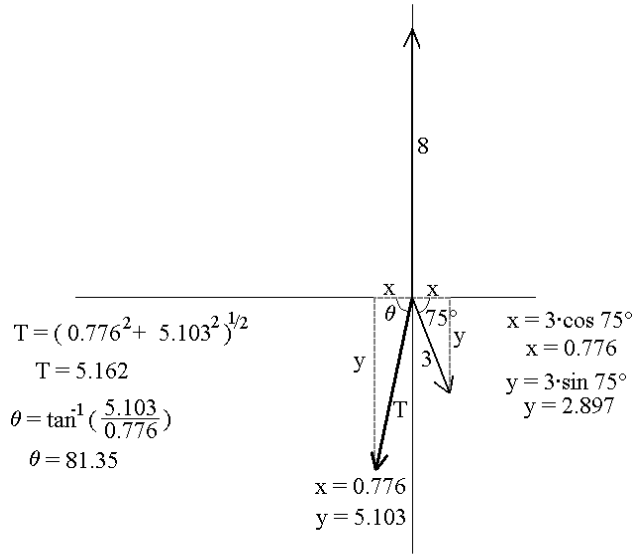
Q6. Was your prediction correct?

Answers will vary and depend upon the answer to Q5.

Q7. Using the head-to-tail method, prove the forces are in equilibrium.



Q8. Predict where the third pulley should be, and how many washers need to be on the hanger for the ring to be centered around the center post.

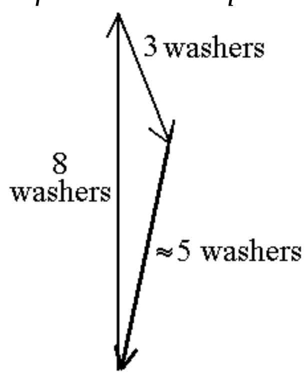


The pulley should be at 188.65° (approximately 189°), with 5.162 washers (approximately 5 washers).

Q9. Was your prediction correct?

Answers will vary, and depend upon the answer to Q8.

Q10. Using the head-to-tail method, prove the forces are in equilibrium.



Situation

Using the same ideas as the previous 3 calculations

 # 1: The necessary vector for equilibrium is approximately 7 washers, with the pulley at 225°. (Actual- 7.07 washers, 225°)

 # 2: The necessary vector for equilibrium is approximately 4 washers, with the pulley at approximately 106°. (Actual- 3.6 washers, 106.2°)

 # 3: The necessary vector for equilibrium is approximately 4 washers, with the pulley at approximately 213°. (Actual- 3.47 washers, 212.64°)

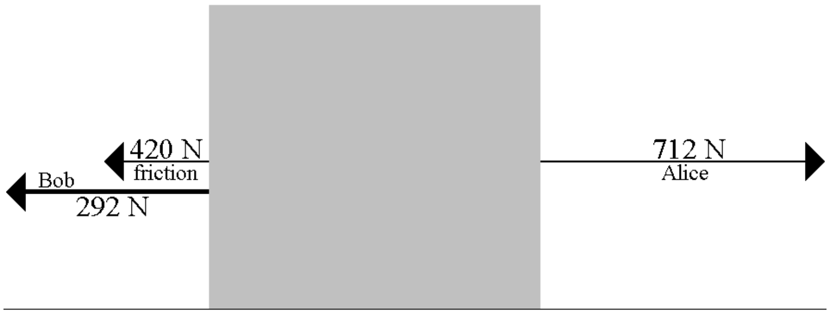
 # 4: The necessary vector for equilibrium is approximately 7 washers, with the pulley at approximately 120°. (Actual- 6.67 washers, 119.9°)

 # 5: The necessary vector for equilibrium is approximately 6 washers, with the pulley at approximately 230°. (Actual- 5.82 washers, 230.43°)

Assessment Answers:

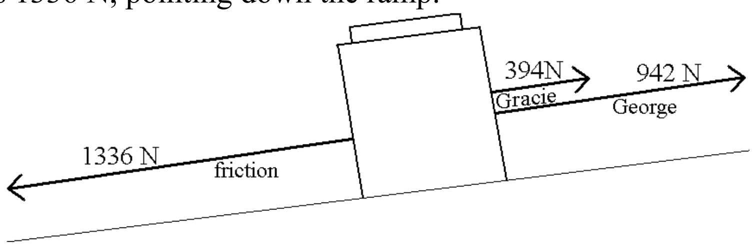
1. Alice is pushing a box across the floor with a force of 712 N to the right. The force of friction between the box and the floor is 292 N. With what force would Bob have to push to stop the box, and from what direction should Bob push?

Bob would have to push the box with a force of 420 N to the left.



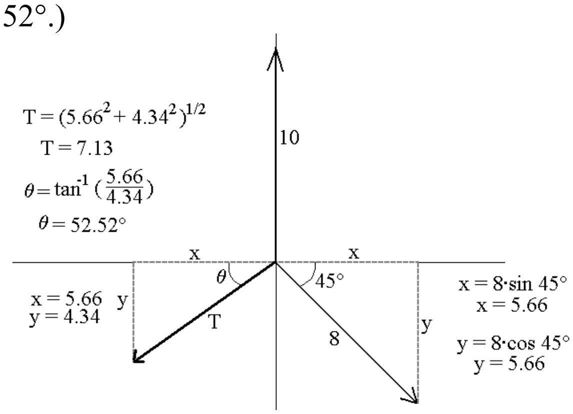
2. George is trying to push a washing machine up a ramp into the house. He is pushing with a force of 942 N. Gracie, trying to help George, pulls the washing machine from the top of the ramp with a force of 394 N. The washing machine does not move. What is the force of friction acting on the washing machine? What direction is the friction force pointing in?

The friction force is 1336 N, pointing down the ramp.



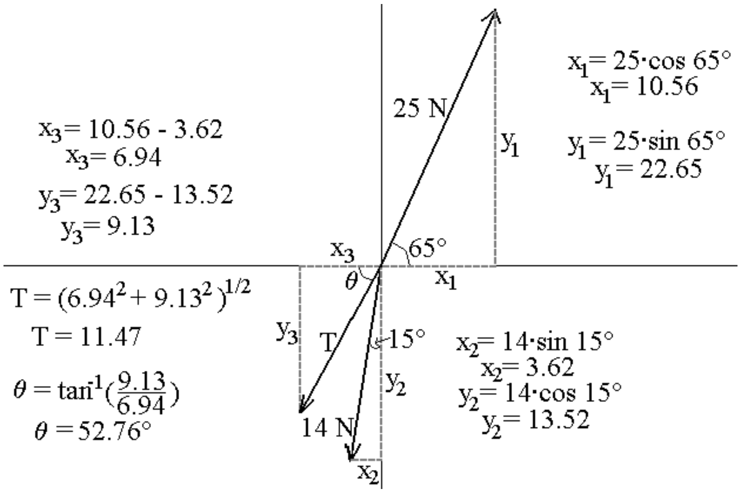
3. A student has a force table set up with one pulley at 0° with 10 washers, one pulley at 135° with 8 washers, and has calculated that the last pulley must be put at 210°, and have 14 washers on the hanger. Is the student correct? If so, prove it mathematically. If not, determine where the pulley should be and how many washers are needed.

The student is incorrect in his calculation of 14 washers, with the pulley at 210°. The correct answer is that there should be approximately 7 washers, with the pulley at approximately 233°. (The actual values are 7.13 washers and 232.52°.)



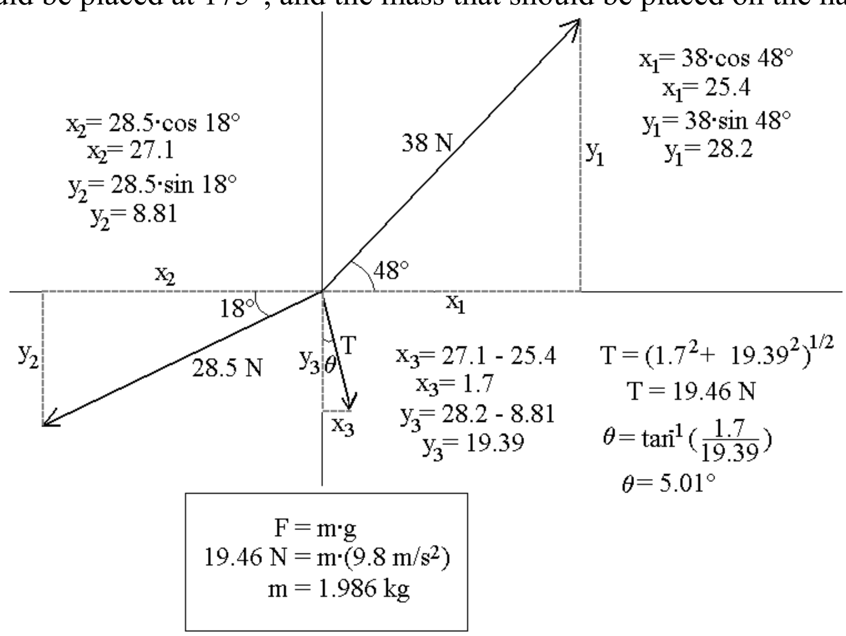
4. A force table is set up so there is a pulley at 25° and one at 195°, with one free to be placed anywhere. The tension in the thread on the first pulley (25°) is 25 N. The tension in the thread on the second pulley (195°) is 14 N. What is the tension in the final thread and where should the pulley be placed?

The tension should be 11.5 N, and the pulley should be placed at approximately 218°. (The actual angle is 217.56°.)



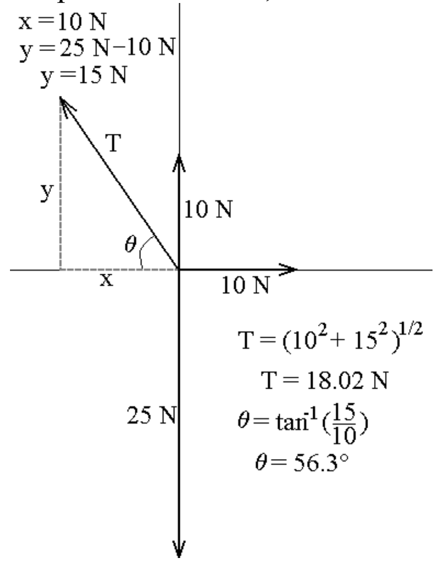
5. A force table is set up with one pulley at 42° with a thread of tension 38 N, and another pulley at 252° with a thread of tension 28.5 N. Where must a third pulley be placed for equilibrium to occur, and what mass (in kg) must be placed on a hanger to get the correct tension?

The pulley should be placed at 175°, and the mass that should be placed on the hanger is 1.986 kg.



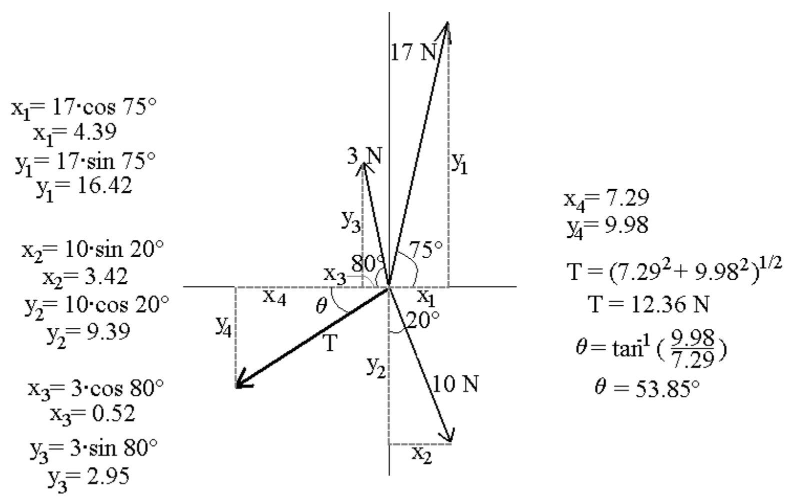
6. Consider a force table set up with four pulleys. One pulley is at 0° with a tension in the thread of 10 N, another pulley is at 90° with a tension in the thread of 10 N, and the third pulley is at 180° with a tension in the thread of 25 N. Where would the fourth pulley have to be placed and what tension would the thread need for the forces to be at equilibrium?

The fourth pulley would have to be placed at 326.3°, with a thread tension of 18.02 N.

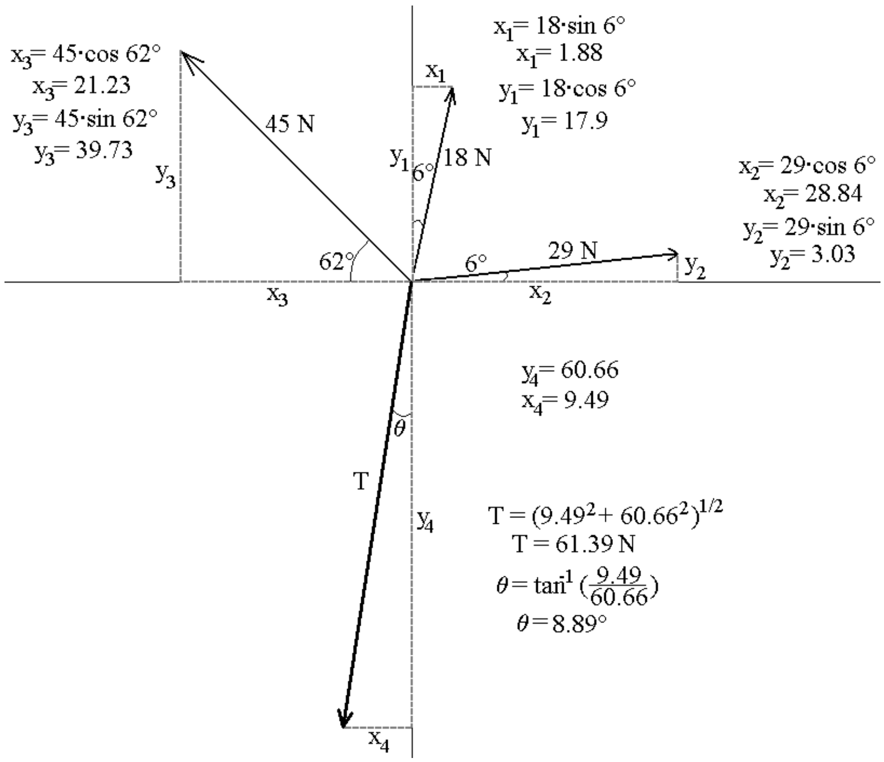


7. A force table is set up with four pulleys- one pulley at 15° with a thread tension of 17 N, one pulley at 160° with a thread tension of 10 N, and one pulley at 350° with a thread tension of 3 N. A student calculates that the fourth pulley would need to be at 216° with a thread tension of 12 N. Is this student correct? Show all your work.

The student is correct with the pulley at 216° (Actual- 216.15°) and a thread tension of 12 N (Actual- 12.36 N).



8. A force table is set up with four pulleys- one pulley at 6° with a thread tension of 18 N, one pulley at 84° with a thread tension of 29 N, and one pulley at 332° with a thread tension of 45 N. What mass (in kg) is necessary to create the appropriate line tension for equilibrium, and where should the pulley be?



The pulley would have to be located at 188.89°.

F = m·g

61.39 N = m · (9.8 m/s^2)

m = (61.39 N)/(9.8 m/s^2)

$\boxed{m = 6.27\text{ kg}}$

The necessary mass would be 6.27 kg.

Suggestions for further study

Below is a possible alternative assessment question, relating the change in gravitational acceleration to a change in mass to keep force the same. The question is based on the values in assessment question 8. All of the values for the gravitational acceleration on other were obtained from planetary data sheets located on NASA's planetary database website, http://nssdc.gsfc.nasa.gov/planetary/. Students can investigate how force is dependent upon the acceleration due to gravity using the values for each planet in the data sheets.

How would the necessary mass change if, instead of on Earth, we were on

a. the moon?
b. Mars?
c. Jupiter?
d. Pluto?

a*. the moon?*

F = m·g

61.39 N = m · (1.62 m/s^2)

m = (61.39 N)/(1.62 m/s^2)

$\boxed{m = 37.89\text{ kg}}$

The necessary mass would be 37.89 kg.

***b**. Mars?*
F = m·g
61.39 N = m · (3.71 m/s^2)
m = (61.39 N)/(3.71 m/s^2)
$\boxed{m = 16.54 \text{ kg}}$
The necessary mass would be 16.54 kg.
***c**. Jupiter?*
F = m·g
61.39 N = m · (24.79 m/s^2)
m = (61.39 N)/(24.79 m/s^2)
$\boxed{m = 2.48 \text{ kg}}$
The necessary mass would be 2.48 kg.
***d**. Pluto?*
F = m·g
61.39 N = m · (0.58 m/s^2)
m = (61.39 N)/(0.58 m/s^2)
$\boxed{m = 105.84 \text{ kg}}$
The necessary mass would be 105.84 kg.

This force table can also be used as a method for alternative assessment. Students can be asked to determine where to properly place pulleys or mass on hangers, and then for assessment can prove their mathematical answers using the force table. It may also be beneficial for students to create free-body diagrams of the masses, the hanger, the thread, or the ring, so they can see what forces are actually acting on the individual objects.

Safety and disposal:

- Eye protection should be worn at all times**.**
- Washers could pose a slipping hazard if left on the floor. Make sure to keep all washers off of the floor when not in use.
- The table stands approximately 43 cm (17 inches) from floor to top of table. Due to its short size, it can pose a tripping hazard. Make sure to keep tables out of walking paths when not in use.