Labatorial 2: Composition of Concurrent Forces[2]

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Pre-Reading:

- *Physics for Scientists and Engineers* by Serway and Jewett (10th ed.), Section:
  - 3.2 – Vector and Scalar Quantities
  - 3.3 – Basic Vector Arithmetic
  - 3.4 – Components of a Vector and Unit Vectors (see in particular Example 3.5)
  - 5.4 – Newton's Second Law
  - 5.5 – The Gravitational Force and Weight
- https://socratic.org/questions/what-are-the-parallelogram-and-the-polygon-methods

Equipment: Experimental box (weights A, B, C, and the collection of masses), pulleys, force table, ruler, protractor, red pen, blue pen, yellow highlighter, calculator

Learning Goals:

- Understanding the various methods of vector addition
- Understanding the concept of equilibrium of forces

Activity 1: Getting a Feeling for Vectors (30-40 min.)

Question 1:

a. List some scalar quantities from classical mechanics and an example for each of where they appear in your everyday life.

b. Do the same as in part (a), but for vector quantities.

Question 2:

a. What are some of the main differences between vector addition and scalar addition?

b. You have read that a resultant force on an object is the vector sum of the forces acting on that object, meaning that the resultant force could replace the individual forces and the acceleration caused would be the same. Now suppose that an **equilibrant** force is the force vector required to balance out all the forces acting on an object. How is the equilibrant force related the resultant force?

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[2] The experiment performed in this labatorial has been adapted from the 2018-2019 lab manual for the course "PHYS 224: Introduction to Experimental Mechanics" at Concordia University.

Question 3:
Bob and Alice are playing tug of war. In Round 1, they both pull with all their might, but the rope remains at a standstill. Unhappy with this draw, they go for Round 2. This time, they end up moving in Alice's direction slowly at constant speed. With this, Alice states that she is the stronger of the two, but Bob disagrees, claiming that they were equally matched both times (considering only the period after they started moving). Depict the pulling forces of Bob and Alice at the ends of the rope as vectors in each situation, keeping in mind that the length of a vector represents its magnitude. How do these two situations differ? Who is right?

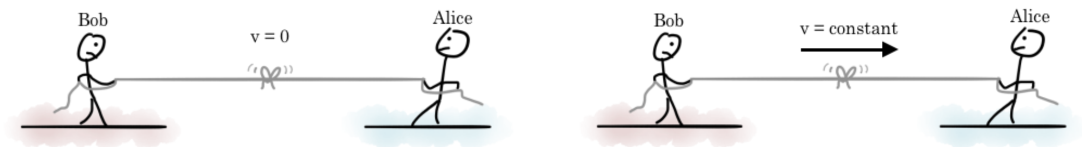
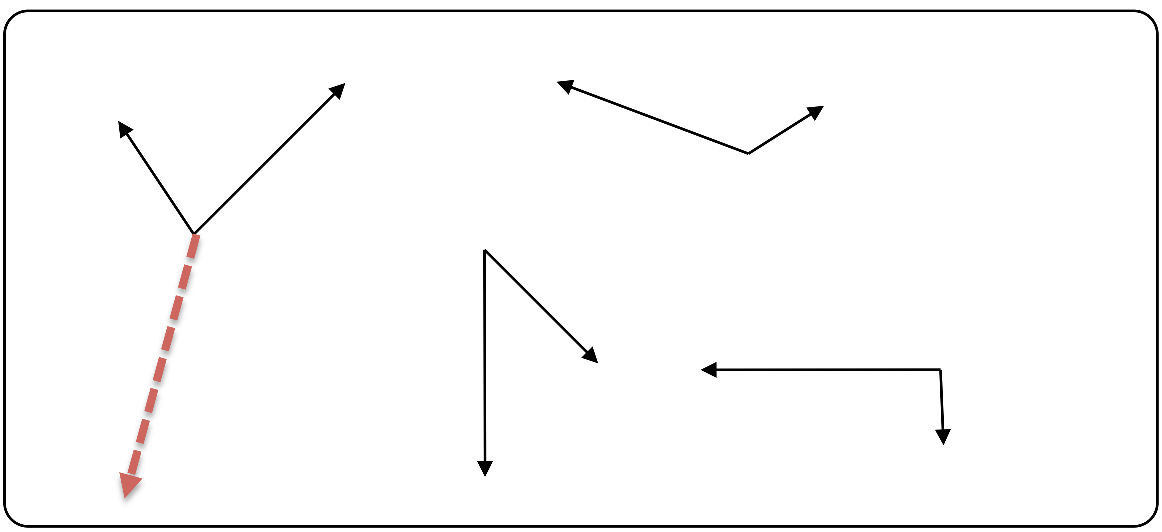


Figure 1 – Bob and Alice's tug of war in each scenario.

Question 4:
For each of the situations below, we have depicted two forces pulling against an object. Directly estimate and draw the equilibrant force for each pair of forces (that is, do it without any extra drawings or written methods). An example is shown. Below, describe the thought process that allowed you to make such estimates.



Checkpoint 1: Before moving on to the next part, have your instructor check the results you obtained so far.

Activity 2: The Surprise Box (90-100 min.)

Question 5:

a. Open your box of masses. The box cover specifies the three particular masses that you will be using for the experiment. We will be comparing their gravitational forces, and so calculate the weight of each mass and record it (along with the specified angle) in the table below. (Show one sample calculation.) For simplicity, round the gravitational acceleration g to $10\ N/kg$, although doing this is not recommended in general.

Table 1 – The Force Vectors from your Experimental Box

	Mass (kg)	**Force (N)**	**Angle (degrees)**
Vector **A**			
Vector **B**			
Vector **C**			

b. When drawing force vectors, an appropriate length scale needs to be chosen since their length corresponds to their magnitude. In all the questions that follow, let **$1\ N$ of force correspond to $3\ cm$ of length**. Use the protractor templates provided at the end of the labatorial to sketch (with a ruler) in pencil the vectors with their **tails drawn from the origin**. On Protractor Template 1, draw only vectors A and C. On Protractor Template 2, draw A, B, and C.

c. By eye, sketch both the resultant and equilibrant forces of the vectors on each protractor template (similarly to Question 4), being sure that all the vectors are labeled with their symbol, magnitude, and angle. These will act as your predictions. We will now verify these intuitive predictions using various methods.

Question 6:

a. Briefly describe the steps of the parallelogram method in your own words.

b. Using the parallelogram method, graphically determine the resultant and equilibrant vectors of **A** and **C** using the grid paper given at the end of the labatorial.

c. In **blue**, also draw the resultant and equilibrant vectors on Protractor Template 1, with their tails drawn from the center and with the correct length and angle.

Question 7:

a. Briefly describe the steps of the polygon method in your own words.

b. Using the polygon method, graphically determine the resultant and equilibrant vectors of **A**, **B**, and **C** using the grid paper given at the end of the labatorial.

c. In **blue**, also draw the resultant and equilibrant vectors on Protractor Template 2.

Question 8:

a. Using the component method, compute the resultant and equilibrant force of **A**, **B**, and **C**. Express both as a magnitude and angle.

Resultant: F = _______________ θ = _________________

Equilibrant: F = _______________ θ = _________________

b. Draw (as precisely as possible) in **red** the resultant and equilibrant vectors on Protractor Template 2. How does the magnitude of this analytical result compare with your intuitive and graphical results from Questions 5c and 7c, respectively? How about the angle? Are they the same? Discuss why you think there are any discrepancies.

Checkpoint 2: Before moving on to the next part, have your instructor check the results you obtained so far.

Force Tables: A force table is an apparatus that can be used to illustrate the composition of concurrent forces. Forces are applied on the force table by hanging masses over pulleys positioned at certain angles. If, for example, two forces are put on the force table, a third force could be added to balance the other two. Therefore, the force table can be used to experimentally determine the equilibrant (and consequently, the resultant) force of a set of specified forces in two dimensions.

Question 9:

a. Place vectors **A** and **C** on the force table with the given magnitudes and angles. By trial and error, find the angle of the third pulley and the mass required to balance the forces exerted by the other two masses. Also record the magnitude and angle of the force below.

   m = ________________ $F_{equilibrant}$ = ______________ θ = ________________

b. Draw (by highlighting in **yellow**) the resultant and equilibrant force vectors on the Protractor Template 1. How does this compare to the intuitive and graphical results obtained in Questions 5c and 6c, respectively? How about the angle? Are they the same? Discuss why you think there are any discrepancies.

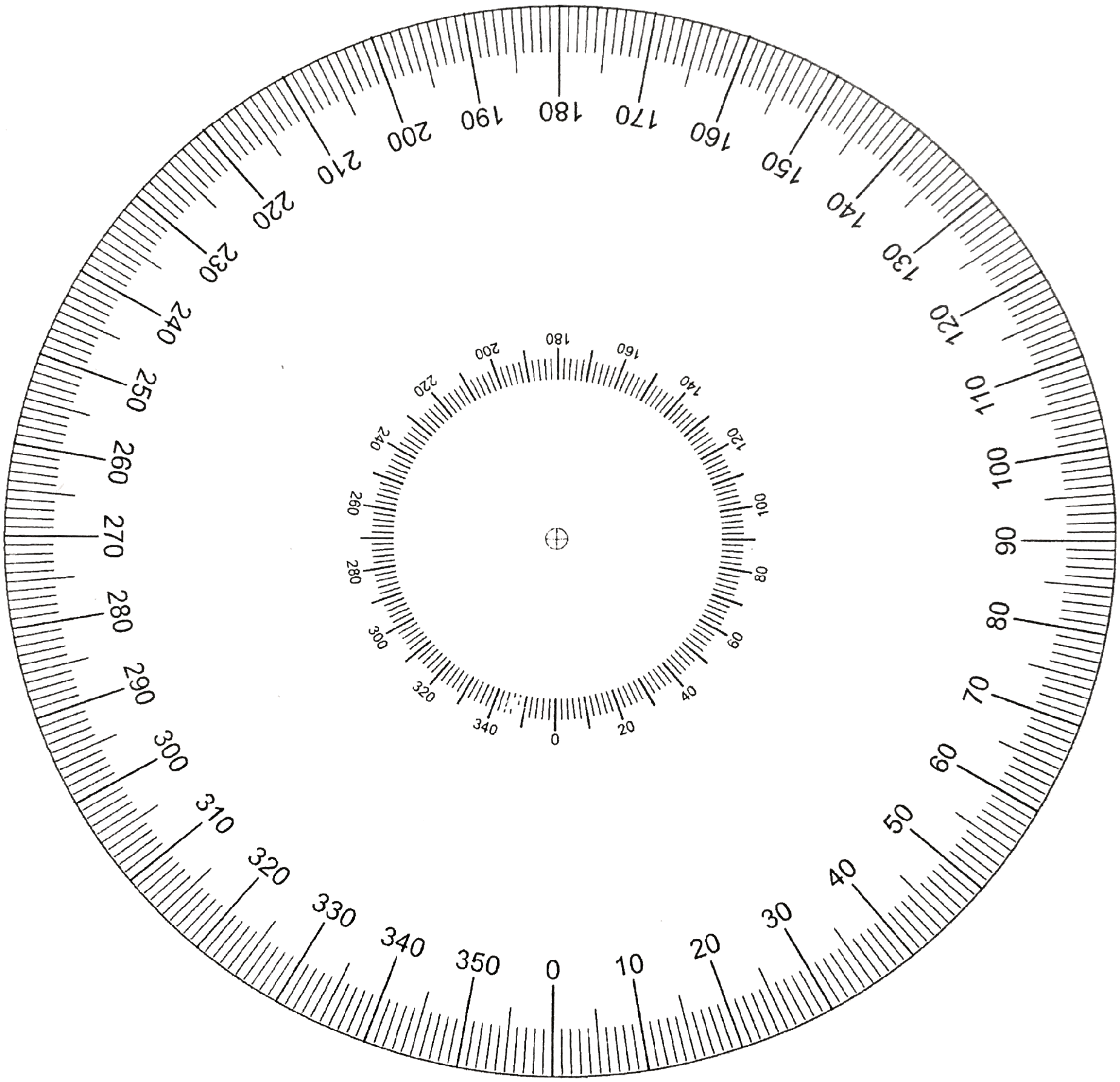
Checkpoint 3: Put all the equipment away and have your instructor check your work before leaving the lab.

Component	Explanations	Points	Mark
Worksheet	• If you finish all checkpoints, you will get 4 points.	4	
Group	• All students must be engaged in the lab activity. • All students must work, discuss, and share their information in the lab. • Interaction with group members and TA is mandatory. • All students must obtain answers to the questions that are the same as the other group members.	3	
Individual	• All appropriate data must be collected. • Data must be well organized and neatly displayed, including graphs. • The results of calculations must be presented with appropriate units. • Related physics concepts must be stated correctly.	3	

Please note that:

- Not properly cleaning the worktable or not putting away equipment that was taken out will result in a 1-point deduction from the "group" component of all members' grades.
- As of Labatorial 2 onward, not bringing your labatorial manual (in which case, a separately printed worksheet will be provided) or pre-reading summary to the lab will result in a 1-point deduction from the "individual" component of your grade.
- Progressing as a group is critical to the success of the labatorial, and so being more than 15 minutes late will result in a 1-point deduction from the "individual" component of your grade. Being more than 20 minutes late means you cannot perform the labatorial and you will receive a 0.

Protractor Template 1



Protractor Template 2