M6a: Physics Tools, Measurements, Vectors, and Analyses

Introduction:

Precise and accurate measurements are the cornerstone not just of physics experiments, but also of physics itself, and the sciences in general. In order to make accurate measurements, it is necessary to take those measurements using the proper instrument. Being familiar with the appropriate use of the equipment is also important. If the correct equipment is being used incorrectly or inaccurately, then the measurements will be flawed. In either case, with incorrect measurements, the results of any experiments will be inaccurate, and the experiment may need to be repeated, resulting in more time spent in the lab.

The focus of this experiment is on learning how to use the different measurement tools properly, and learning how to select the measuring tool with the appropriate precision for the task. By taking several different measurements of mass and length for different objects, it becomes possible to familiarize oneself with the West Campus Physics Laboratory's measuring instruments. This familiarity will prove to be extremely important for all future physics experiments performed throughout the semester.

After collecting the different measurements, those values will be used to calculate area, volume, and density of materials the objects are made of. Remember, when collecting data and taking measurements, and also when performing calculations, to pay careful attention to the units of measurement; units of measurement must be consistent. Also, all measurements used for experiments performed here in the lab should be made in **SI** units (meters, kilograms, and seconds), unless explicitly stated otherwise. Once all calculations have been completed, some simple statistical analysis will be performed on the data.

Finally, vector addition and subtraction will be performed graphically and analytically. The vector results will be demonstrated and confirmed using a vector force table, with masses approximating vector lengths. **Time spent in the Physics Lab can be greatly reduced if the vector calculations from Part V of the Procedures section are done before arriving at the lab**.

Apparatus:

- 1 long cylinder
- 2 *plastic* cubes of similar volume
- 4 items of different *shape* and *volume* but similar material
- 5 different lengths of wire cut from the same spool
- 1 precise metal ruler
- 1 meter stick
- Vernier & digital calipers
- micrometer & digital micrometer
- 2 different electronic balances
- 1 vector force table
- 1 set of assorted masses

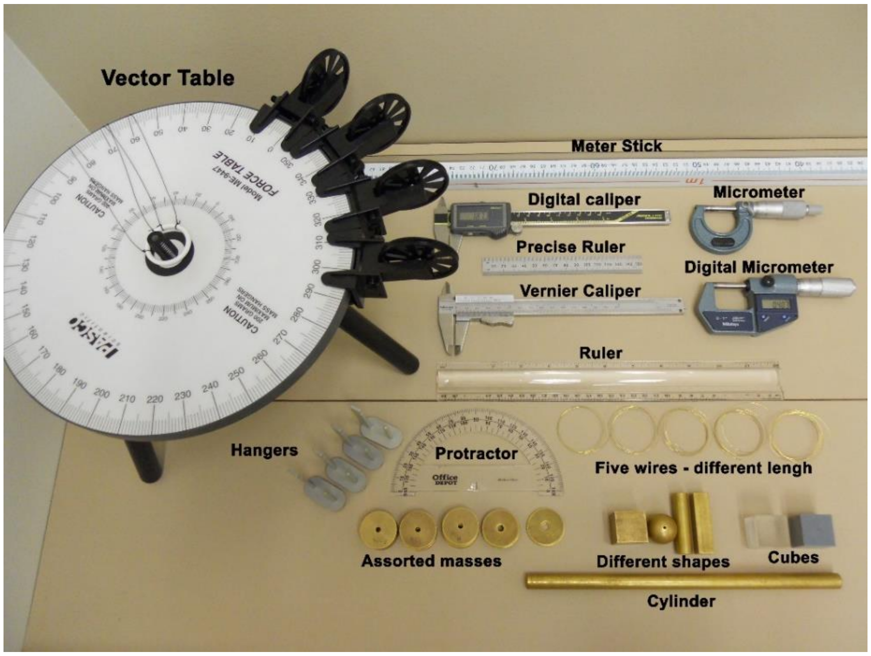

Figure 1. M6a lab kit.

Procedures:

This lab consists of four small sub-experiments, all of which are related to the central concept of measurement, and all of which are geared to providing the understanding necessary in order to operate the different measuring apparatuses in the physics laboratory. Be sure to follow the instructions to each of the four different parts of this experiment exactly. **Also, please be sure to seek assistance from a lab instructor before beginning any experiment.**

PART I. Density of Plastic Cubes

1. There are multiple laboratory balances located throughout the Physics Lab. Select the two plastic cubes (grey and clear) and measure the mass of each on all these balances, in order to gain familiarity with their different accuracies. Keep in mind that if a mass is too heavy for a balance, it will not give a reading.
2. Record only two of the mass measurements: one of the measurements of mass should be from the most precise balance in the lab, and the other measurement should be taken from the least precise balance in the lab. Record this information in the provided table (Data Table I**)**. Take careful note of any variations in the mass between these two balances, and be prepared to offer possible explanations for any observed discrepancies if required by your instructor.
3. Measure the length, width, and height of both of the plastic cubes. Do so first with the precise metal ruler (rule), and then with the non-digital micrometer. Record these measurements as well; again, being sure to take note of any variations in the measurements, paying careful attention to any difference in precision between the two measuring tools.
4. Calculate the volume and the *volumetric* density of each cube using the measurements obtained with the micrometer and the most precise electronic balance. Volumetric density, ρ, is often called simply density. Average volumetric density is defined as the ratio of total mass of an object, ***M***, to its volume, ***V***:

$$\rho = \frac{M}{V}$$

PART II. Mean and Standard Deviation of Diameter of a Cylinder

1. Select the longest cylinder from the **M6a** lab kit. Gradually moving along the length of the cylinder, measure its diameter in ten different places using the Vernier caliper. Record these measurements in the provided table (Data Table II).
2. Calculate the mean (average) diameter of the longest cylinder and its standard deviation. The standard deviation is a statistical quantity which provides a sense of the spread of the measurements around their mean value. These values can be calculated by using the following formulas or by using a list in a graphing calculator or Microsoft Excel.

$$\text{Mean} = \frac{\sum \chi}{n} \qquad \text{Standard Deviation} = \sqrt{\frac{\sum\left(\chi^2\right) - \frac{\left(\sum \chi\right)^2}{n}}{n-1}}$$

χ = *a measured value (datum)*

n = *the number of measured values*

PART III. Density of Objects of Different Shape

1. Measure the dimensions of each of the 4 items of different shape (similar material) using digital calipers. Record this information in the provided table (Data Table III).
2. Measure the mass of each item (*obtain the greatest possible precision*).
3. Calculate the volume and density of each item.

PART IV. Linear and Volume Mass Densities of a Wire

Linear density, **μ**, is the mass per unit length of an object. It is often used in place of volumetric density to describe objects which have one dimension substantially larger than all others (for example, a thin wire), or objects with properties that vary in only one dimension. Average linear mass density can be calculated by dividing total mass of an object, ***M***, by its total length***, L***:

$$\mu = \frac{M}{L}$$

It can also be determined from an analysis of the plot of the mass of the objects (with similar material and cross-sectional area) as a function of the length of the objects

1. Measure the length of each piece of wire as accurately as possible by using the most precise tools of measurement available.
2. Measure the mass of each piece of wire using the most precise electronic balance available.
3. Measure the diameter of each piece of wire using the digital micrometer. When measuring the wire's diameter, one should select a smooth section of wire, without any bends or kinks.
4. Calculate the volume and *volumetric* density of each piece of wire.
5. Calculate the mean and standard deviation of the density.
6. Calculate the linear density of the wires by graphing the mass of each wire on the Y-axis, and the length of each wire on the X-axis, and then by finding the slope of the straight line that best fits the data (the least-squares regression or "trendline" in Excel). It is recommended that this calculation be done in Microsoft Excel.
7. Record the equation of the obtained best fit line and the correlation coefficient R. The correlation coefficient shows how well your experimental points follow a theoretical line. **If there any questions on how to use Microsoft Excel, please see a lab instructor.**
8. Record standard deviation.

PART V. Vectors Addition and Force Table

PART V of this experiment is divided into three different sections. Both **SECTION A** and **SECTION B** require only calculations, and can be done outside of the lab. In both of these sections, vectors will be added and subtracted graphically and analytically. In **SECTION C** the results of those calculations will be checked by physically approximating the vectors on a vector force table.

SECTION A.

1. **Graphically** add the following two vectors using the head-to-tail method. Please check the example given in **Figure 2** and reference any of the physics textbooks available in the Lab for more information on the head-to-tail method of adding vectors, if necessary. It is recommended that the origin for the first coordinate axis be positioned in the middle of the page in order for everything to fit. **Draw the vectors exactly to scale.**

$\vec{A} = 10.0cm @ 60°$

$\vec{B} = 8.0cm @ 170°$

find: $\vec{R} = \vec{A} + \vec{B}$

All angles are measured counterclockwise from the +x-axis.

2. Find and label the resultant, $\vec{R}$. Using a protractor and ruler, give its magnitude and direction (from the +x-axis). For ***SECTION A*** and ***SECTION B*** of this experiment it is very important that all data be clearly labeled and organized in a readable manner.

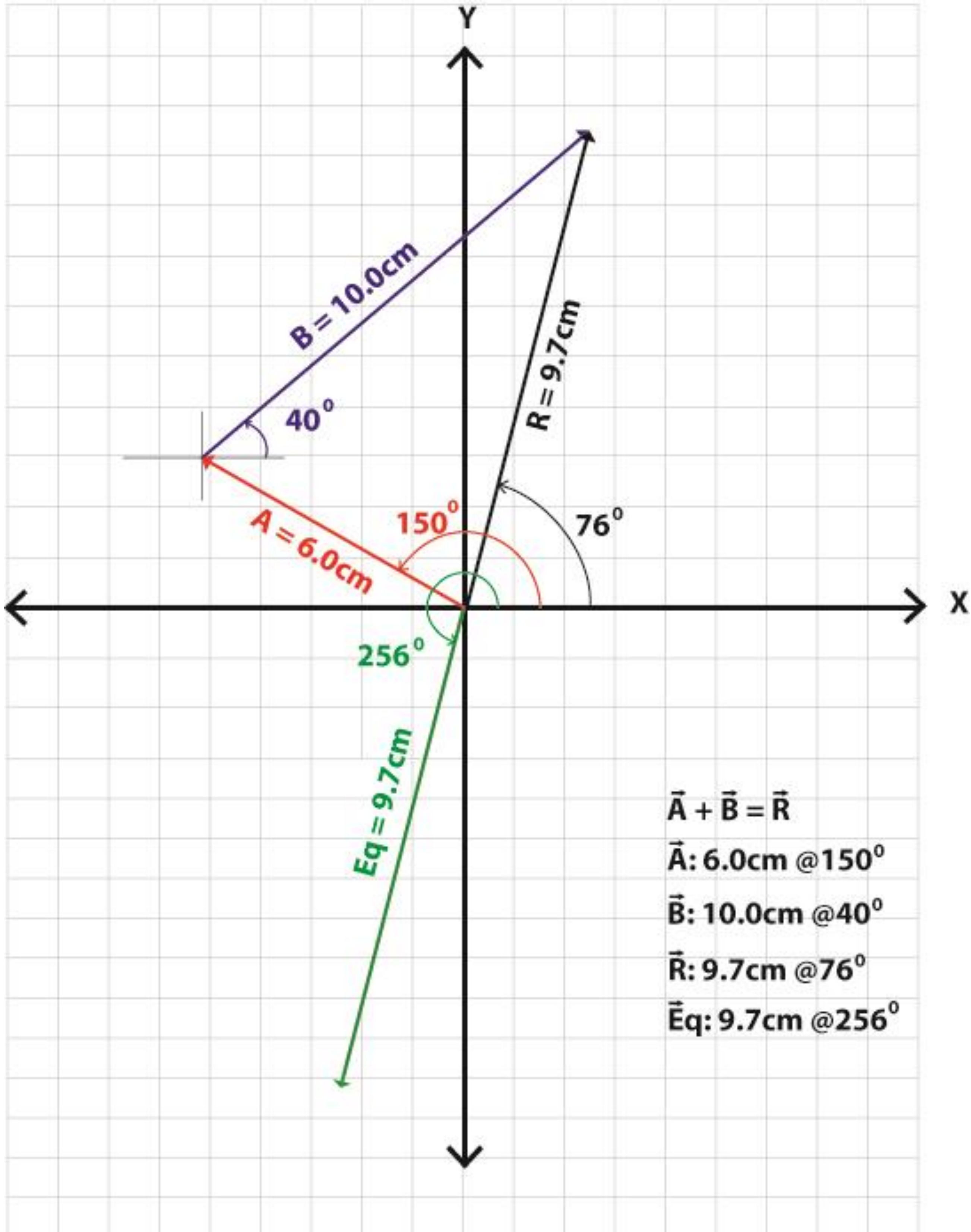

Figure 2. Example of "Head-to-Tail" method of adding vectors.

3. **Analytically** determine the magnitude and direction of the resultant, $\vec{R}$. Begin by mathematically finding the *x* and *y* components of $\vec{A}$ and $\vec{B}$. Once again, please consult any physics textbook for help regarding vector components. Next, calculate the sum of the *x* components and the sum of the *y* components. Finally, use the sums of the components in conjunction with the Pythagorean Theorem and the arctangent function to determine the resultant. **NOTE: Show your work in a separate page including the equations for the calculations and record all of this information on the provided Data Sheet**.

4. Provided below are several different formulas used for examining the error in an experiment. These formulas will be utilized throughout the semester, and for that reason it will be necessary to become familiar with each formula. *Theoretical* is an accepted or mathematically calculated value of a quantity. *Experimental* is a value obtained based on measurements in an experiment.
   Making sure to choose the correct formula, please find the **percent error or percent difference** for the graphically determined angle and the angle calculated via the vector component method. Repeat these calculations for the magnitudes.

$$\text{percent error} = \left| \frac{x_{\text{experimental}} - x_{\text{theoretical}}}{x_{\text{theoretical}}} \right| * 100\% \qquad \text{standard error} = \frac{\text{standard deviation}}{\sqrt{n}}$$

$$\text{percent difference} = \left| \frac{x_{\text{experiment1}} - x_{\text{experiment2}}}{x_{\text{average1\&2}}} \right| * 100\%$$

5. The *equilibrant* is defined as a vector equal in magnitude to the *resultant* but rotated by180° *or* opposite in direction. The equilibrant is the vector that cancels out the resultant vector. If one were to use the head-to-tail method to graphically add the equilibrant of $\vec{R}$ to $\vec{R}$, then the resultant vector would be 0. Find and label the equilibrant of $\vec{R}$ and draw it on the vector diagram. Also, find its magnitude and angle using the analytical method.

SECTION B

Repeat the above procedures (steps 1-5 from ***SECTION A***) for the following 3 vectors, keeping in mind the idea of the equilibrant, which might be useful. Be sure, when combining the vectors via the head-to-tail method, to use separate sheet of paper from ***SECTION A***'s graph.

$\vec{C} = 10.0cm @ 30°$

$\vec{D} = 10.0cm @ 160°$

$\vec{E} = 5.0cm @ 230°$

find: $\vec{R} = \vec{C} + \vec{D} - \vec{E}$

All angles are measured counterclockwise from the +x-axis.

SECTION C

1. Now that the resultants and equilibrants for both ***SECTION A*** and ***SECTION B*** have been found, it is necessary to physically check the results of the experiment using a vector table. First set up the appropriate number of pulleys at the appropriate locations. The pulleys should be aligned at the appropriate angles corresponding to the vectors they approximate. For checking the results from ***SECTION A***, 3 pulleys will be needed ($\vec{A}, \vec{B}$, and the *Equilibrant*), and then for confirming ***SECTION B,*** 4 pulleys ($\vec{C}$, $\vec{D}$, $-\vec{E}$, and the *Equilibrant*).
2. Once the pulleys have been set up, it will be necessary to approximate the vectors lengths by utilizing masses. For this experiment, let ***10 grams*** approximate ***1.0 centimeter***. Find the mass required for each of the corresponding vectors.
3. Use the light mass hangers provided, as well as the masses in the mass kit to compile the required mass for each vector. If a mass included in the mass kit is not labeled, it is possible to check its mass on any of the laboratory's balances (rounding the measured mass to the nearest whole number). Please keep in mind that the mass hangers themselves will factor into the total mass hanging from the strings, and must be taken into account.
4. Once the appropriate masses have been assembled, connect the mass hangers and their masses to the strings connected to the ring on the vector table.
5. Physically check your resultant by using the appropriate equilibrant. Place the corresponding mass for the resultant at the angle you previously determined for the equilibrant. The system should remain in equilibrium (balanced and centered around the vector table pin in the center of the vector table). **Please make sure to have a lab instructor confirm that the system is balanced for both physical representations of *SECTION A* and *SECTION B*.**

   If required by your instructor, take notes to describe and explain the equilibrium state of your vector table for the lab write up.

Please do not draw SECTION A and SECTION B on the same page. Also, please be sure to include the equilibrant for each graph on the same page as the vectors were graphically drawn.

Experiment M6a: Measurements, Vectors, and Analyses

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor____

Experiment Start Date____

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: M6a: Measurements, Vectors, and Analyses

NAME: ___________________________ DATE: ________________

TABLE I

	1st Mass Measurement (g)	2nd Mass Measurement (g)	1st Dimensions rule (mm)	2nd Dimensions micrometer (mm)	Volume (cm^3)	Density (g/cm^3)
Cube 1			**L:**	**L:**		
			W:	**W:**		
			H:	**H:**		
Cube 2			**L:**	**L:**		
			W:	**W:**		
			H:	**H:**		

TABLE II

Trial #	Measured Diameter (mm)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Mean: ________________ Standard Deviation: _______________

Data Sheets: M6a: Measurements, Vectors, and Analyses

NAME: ______________________________ DATE: __________________

TABLE III

Item Description	Dimensions (mm)	Mass (g)	Volume (cm^3)	Density (g/cm^3)

TABLE IV

wire	Mass (g)	Length (cm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
1					
2					
3					
4					
5					

Linear Density: Slope ______________ Standard Deviation ______________

Density: Mean ______________ Standard Deviation ______________

1. **Briefly explain why there are discrepancies in the different measurements (mass and dimensions) of the cubes (Table 1). Also explain why there are discrepancies in the different measurements for the diameter of the cylinder (Table 2).**

2. **Briefly explain what is a volumetric and a linear density.**

Data Sheets: M6a: Measurements, Vectors, and Analyses

NAME: ______________________________ **DATE: __________________**

TABLE V

SECTION A: $\vec{R} = \vec{A} + \vec{B}$

Graphical (Head-to-tail) Method of Vector Addition	
Magnitude of $\vec{R}$ (measured with ruler):	
Angle of $\vec{R}$ (measured with protractor):	
Magnitude of the Equilibrant (measured with ruler):	
Angle of the Equilibrant (measured with protractor):	

Component Method of Vector Addition			
A_x		A_y	
B_x		B_y	
R_x		R_y	
Magnitude of $\vec{R}$ (calculated):			
Angle of $\vec{R}$ (calculated):			
Magnitude of the Equilibrant (calculated):			
Angle of the Equilibrant (calculated):			

% Error for Magnitude of $\vec{R}$
% Error for Angle of $\vec{R}$

Show Calculations for Component Method of Vector Addition below:

Data Sheets: M6a: Measurements, Vectors, and Analyses

NAME: ____________________________ **DATE: ________________**

TABLE VI

SECTION B: $\vec{R} = \vec{C} + \vec{D} - \vec{E}$

Graphical (Head-to-tail) Method of Vector Addition	
Magnitude of $\vec{R}$ (measured with ruler):	
Angle of $\vec{R}$ (measured with protractor):	
Magnitude of the Equilibrant (measured with ruler):	
Angle of the Equilibrant (measured with protractor):	

Component Method of Vector Addition			
C_x		C_y	
D_x		D_y	
E_x		E_y	
R_x		R_y	
Magnitude of $\vec{R}$ (calculated):			
Angle of $\vec{R}$ (calculated):			
Magnitude of the Equilibrant (calculated):			
Angle of the Equilibrant (calculated):			

% Error for Magnitude of $\vec{R}$
% Error for Angle of $\vec{R}$

Show Calculations for Component Method of Vector Addition below: