Semester I lab quiz Study Guide (Mechanics)
Physics 135/163 - Includes variations for virtual labs

Students work alone on lab quizzes.

In this guide, lab titles/topics are listed alphabetically, with a page break in between each one. There will be labs listed that you did not perform this semester; don't worry about them.

You are always allowed to refer to your own handwritten lab notebook, pre- and post-lab exercises, and handouts that your instructor may have provided.

Fall 2021: For in-person labs, you MAY refer to the printed lab manual. Remote learning labs, if applicable: you may refer to the Sakai site.

Questions and tasks on the lab quizzes are based directly on what you have learned and done in lab activities. Therefore you should expect to turn in a perfect quiz if your lab notebook is complete, detailed, well-written and explains completely how you carried out activities and interpreted them.

Patience and extreme care will be rewarded, but as in real life, careless mistakes will be costly.

TIPS:

Read the descriptions and sample questions, discuss them with your lab partners before the quiz, and please come in with any questions.

Be familiar with the experiments, calculations and concepts.

Check your work and pay attention to details; verify and include units, label graph axes, read and use your calculator carefully.

Keep a neat lab notebook with diagrams and details, and **answer all questions with full sentences** in your lab notebook.

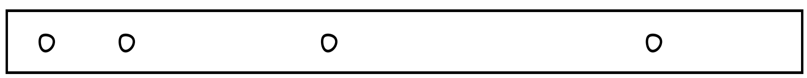
Be able to reproduce any similar experiment, calculation or explain a concept from the labs.

Acceleration in Freefall: Tape Timer

Given a strip of tape with marks on it, supposedly recorded on another planet in a free-fall tape-timer experiment, deduce what the acceleration due to gravity is on the alien planet. The time interval between markings will probably differ from 1/40 sec.

SAMPLE
You are performing a tape timer and freefall experiment on Planet X. Four spots from your tape (actual size) are shown below, separated in time by 0.040 ± 0.001 s. Call them points 0, 1, 2, and 3.

(Use 3 or 4 significant digits in this problem, and show all work.)



a. Find the speed of the object at t1 and at t2. Include units, and significant figures.
b. Using the previous results, find the acceleration due to gravity on Planet X, which you may assume is constant. Include units.
c. Given a graph of data, draw a best-fit line by hand, and calculate the slope of the best-fit line.

DISTANCE LEARNING VARIATION
You will be provided with a picture of the dots printed on ruled paper, that also contains a scale, or else you will be provided with numerical data, which represent the positions of a series of dots.

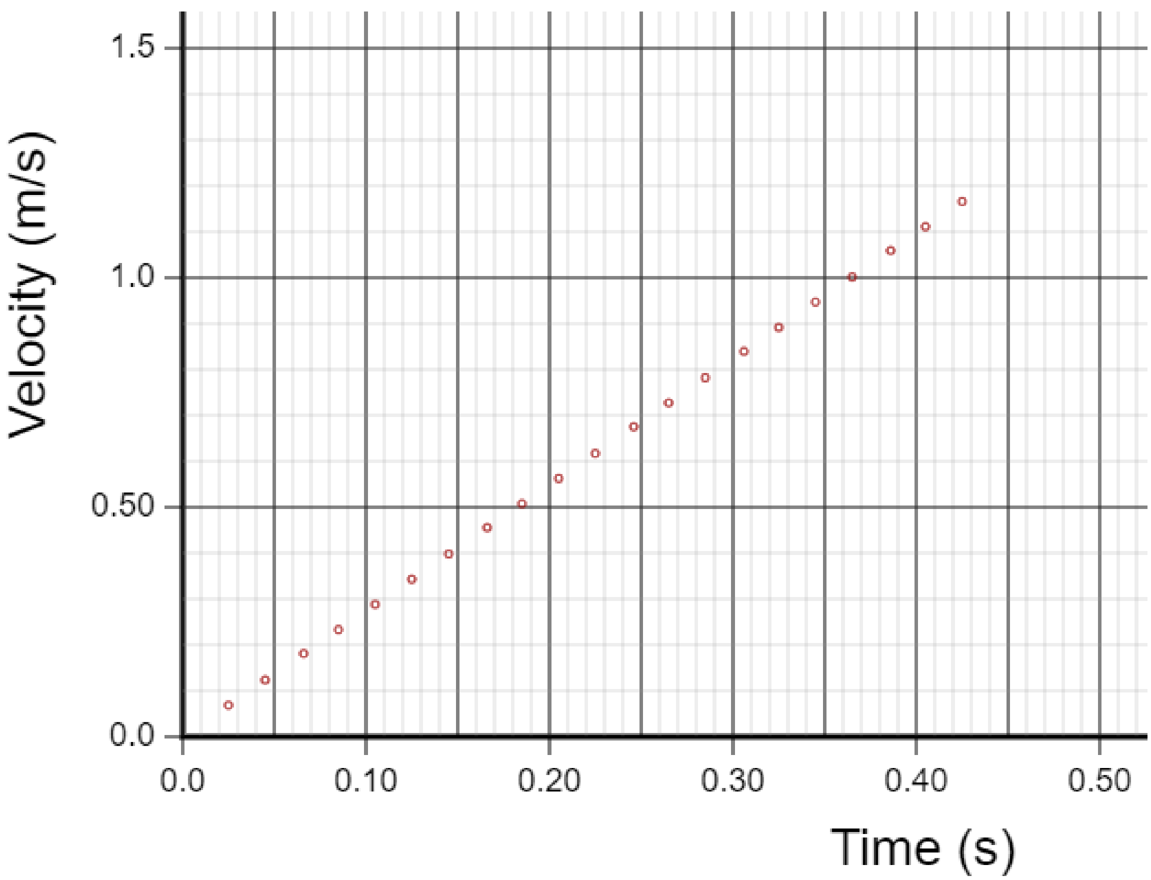
Atwood's Machine

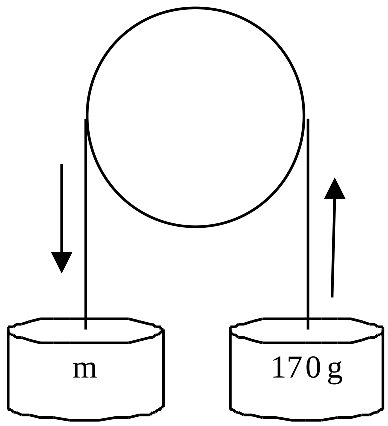
Given an Atwood's machine situation and the value of both masses, use the computer and/or theoretical calculation to measure/determine the acceleration of the system, or the tension.

Or, given one of the two masses, and either the magnitude of the system's acceleration or the string tension, deduce the unknown mass.

SAMPLE 1

A string runs over a frictionless, massless pulley. Two blocks hang from the string. When the system is released from rest, the system begins to accelerate as shown. The velocity vs. time points shown are collected by the computer interface, using the Smart Pulley sensor.





You have measured one of the masses, as shown in the figure.
a. What is the acceleration of the system? Include units. (study guide answer: you would first find the slope, 2.74 m/s^2, which is the acceleration. Units must be included.)
b. Calculate the mass m of the other block. Include units. (Use the equation given in lab that relates the 2 masses to the acceleration (which we just found), and the one mass we know, to solve for the other mass of 302 grams. By the way, if you got 95.7 grams, you're on the right track, but that answer makes no sense. Look at the diagram to see why.)
c. Calculate the tension in the string. Include units. (We know both masses so we can solve for the tension, 2.13 N)

SAMPLE 2
A string runs over a frictionless, massless pulley. Two blocks hang from the string. The heavier mass is 95 grams. The string tension is 0.88 N.

The curve fit to the velocity data is given by $v_y = 0.001+0.54*t$. What is the other mass? (study guide answer: 85 grams. You can find this answer in 2 distinct ways: by using the acceleration only, or by using the tension only. We recommend that you do it both ways and verify that the answers are the same.)

<u>Collisions in 1-D: Linear Momentum and KE</u>

Be able to describe the types of collisions (elastic and inelastic) and whether or not momentum and/or kinetic energy is conserved for each of these.

Given the masses of 2 carts on an ideal frictionless airtrack, and the velocity either before or after a collision, calculate the system momentum and kinetic energy, or the individual momentum (with sign) and KE of a cart.

Given the system's momentum or kinetic energy before the collision, predict that the system's momentum and KE should be the same after an elastic collision. However, if the carts stick together, the momentum should be the same though the KE must go down.

Suppose you were given complete data for the carts before the collision, and partial data for the carts after the collision (or vice versa). Be able to use the conservation of momentum principle to solve for unknowns such as the velocity (speed and direction) of either cart, or the mass of either cart.

EXAMPLE 1: Two air carts have total masses m1=320 grams and m2=195 grams. Assume that there are absolutely, positively, undoubtedly, unequivocally <u>no</u> frictional or other external, horizontally directed forces acting on the system of the two air carts.

Initially, cart #1 is moving to the right and cart #2 is moving to the left. Cart #1 has a speed of 0.324 m/s, and Cart #2 has a speed of 0.766 m/s. Then the two carts collide and stick together.

a. Using your knowledge of physics, determine the expected *momentum* of the system AFTER the collision. Make sure you designate which direction is positive. Remember units! (-0.0457 kg m/s, with positive being to the right)
b. What is the total kinetic energy <u>before</u> the collision? Again, remember your units! (0.0740 J)
c. Consider the KE <u>after</u> the collision. In this ideal experiment, do you expect it to go down, go up, or remain the same? Why? (It goes down, because anytime objects collide and stick together, KE always goes down. Method 2: Use momentum conservation to find that the velocity afterward is -0.0887 m/s, then use the KE formula to find KE of 0.00203 J. This is indeed far less KE than there was before the collision.)

EXAMPLE 2: A 210-gram cart moves right at a speed of 5.00 m/s and collides with an unknown mass car moving left at a speed of 4.00 m/s. They stick together and move toward the left at a speed of 0.576 m/s. What is the unknown mass? (342 grams) What is the momentum before the collision? (-0.318 kg m/s) What is the % change in the system's KE? (-98.3%)

<u>Conservation of Angular Momentum</u>

Given data on two disks, such as masses and inner/outer diameters/radii, and the initial angular velocities of the 2 disks, use the conservation of angular momentum principle to calculate the common angular velocity after the two disks are allowed to contact each other and spin together.

Or, given the common final angular velocity, solve for unknowns such as the initial angular velocity of one of the disks.

Or, given data on the starting and final angular velocities and some data on the disks, solve for unknowns such as moments of inertia, masses or diameters/radii.

EXAMPLE

Two metal disks have masses m1=3.45 kg and m2=UNKNOWN kg, and each has a radius of 8.31 cm. (You may ignore the inner hole for both disks - assume that it is very small.) They spin on cushions of air in a standard rotational dynamics apparatus. Initially, disk #1 is spinning counterclockwise at 6.02 rad/s and disk #2 is spinning clockwise at 2.50 rad/s. A pin is removed that drops disk #1 onto disk #2. After a short time they are seen to spin at the same angular speed of 2.33 rad/s, counterclockwise. Assume that there are <u>no</u> outside frictional forces acting on the system of the two disks.

a. Calculate the moment of inertia of the first disk. Include units.

(0.0119 kg m^2)

b. Calculate the mass of the second disk in this ideal situation. Include units.

(2.63 kg)

Friction

Be able to calculate, for both kinetic and static friction:

a. The frictional force, given the mass and coefficient of friction, including experimental uncertainty.
b. The coefficient of friction, given the mass and frictional force, including experimental uncertainty.
c. The mass or the normal force, given the friction coefficient and the applied frictional force, including experimental uncertainty.

Be able to sketch a force diagram for a block either at rest or sliding, with friction.

Example 1:
A block of wood with a mass of 220 g (assumed exact) is sitting on a surface, where the coefficients of static and kinetic friction between the materials are $\mu_s = 0.31 \pm 0.01, \mu_k = 0.22 \pm 0.01$.

What force is required to get the block moving? Quote your answer including an experimental uncertainty. ($0.67N \pm 0.02N$)

Once the block is moving, what horizontal force is required to keep the block sliding at constant speed? Quote your answer including an experimental uncertainty. ($0.47N \pm 0.02N$)

Example 2:
A block of wood just starts moving when a horizontal force of $1.5 \pm 0.1N$ is applied to it. The coefficients of friction between the block and the table are $\mu_s = 0.29 \pm 0.01, \mu_k = 0.19 \pm 0.01$.

What is the mass of the block, to the nearest gram? (528 grams)

Once the block is moving, what horizontal force is required to keep the block sliding at constant speed? Quote your answer including an experimental uncertainty. ($0.98N \pm 0.05N$)

<u>Hooke's Law</u>

Perform calculations similar to those you performed in lab.

SAMPLE

Similar to Part 1 of the Hooke's Law Lab you watched and analyzed, a spring is suspended vertically with just enough mass on it so that it stretches just a bit.

This initial total length of the spring is recorded as "the unstretched length."

Now, for the experiment, more mass is added three times and the total length of the spring is recorded each time. The initial length is subtracted off, like it was in the lab video, to get the additional stretch, x. The data points are recorded in this table.

Data Table

Total Additional Mass (kg)	Additional Tension in Spring (N)	Total Additional Stretch x (m)
m_1= 0.071	F_1	0.04
m_2= 0.191	F_2	0.12
m_3= 0.327	F_3	0.21

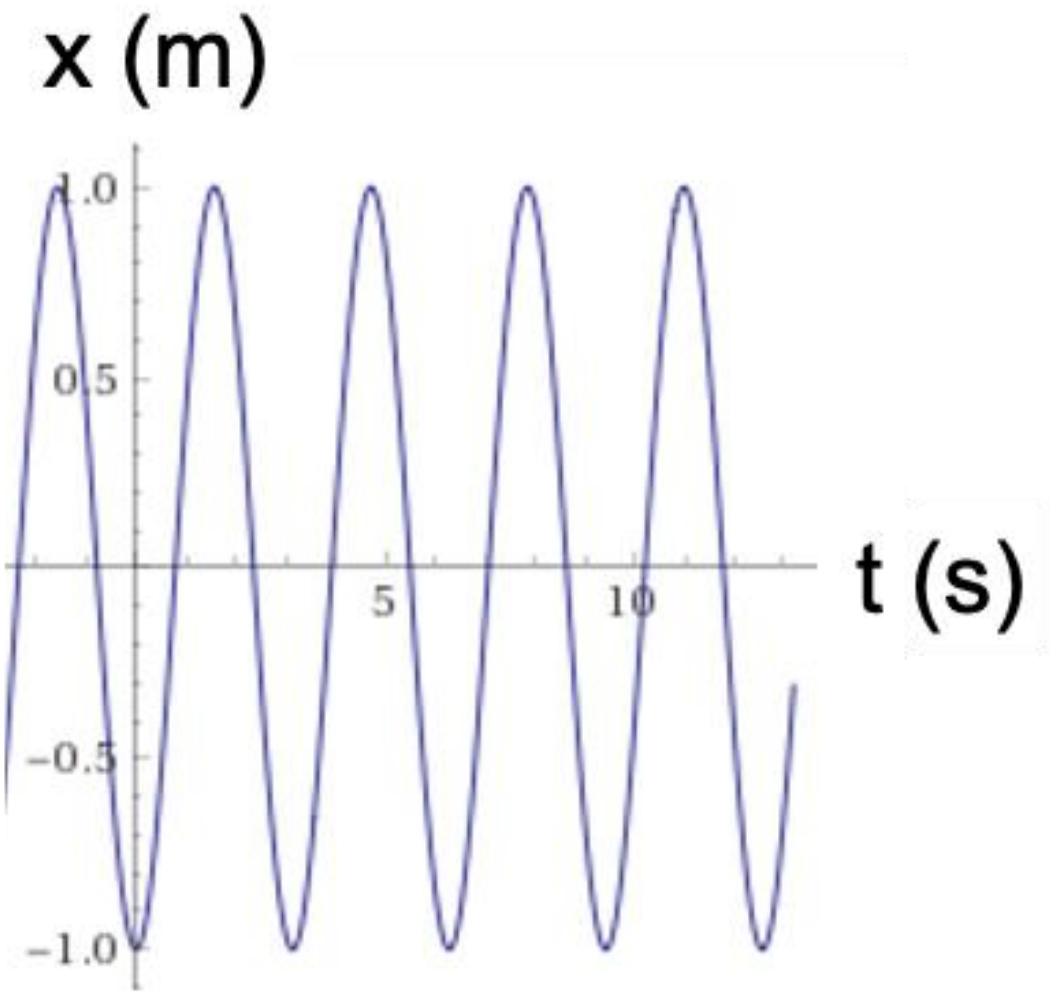
a. What are the missing values on the middle column of the table. Write "F1= ________, F2=_______, F3=_______." Include units.
b. Construct an appropriate graph to find the spring constant k (either on graph paper or in a graphing program). (Tip: always check if a graphing program, like Excel, is graphing the axes you intended it to graph.) You do not need to submit this graph, but tell which variable you put on the vertical axis, which variable on the horizontal axis and how you used this graph to find k.
c. What did you find for the spring constant of this spring? Include units.

Study guide answers:
a. F1= 0.6958 N, F2= 1.87 N, F3= 3.205 N
b. For the graph, put the force values on the vertical axis and the total additional stretch values on the horizontal axis. The value for k is the slope of the resulting line.
c. k= 14.8 N/m

SAMPLE

A mass of 101g suspended from a long spring is allowed to oscillate up and down.
This is <u>not</u> the same spring as in the previous question. In fact, this one has very thin coils and doesn't look very stiff at all.
The motion is graphed on a graph of position on the vertical axis (measured from the unstretched position) and time (in seconds) on the horizontal axis.

The mass is allowed to bounce a number of times before the experiment is stopped. Here is what was collected by the experimenters.



a. From the data provided, estimate the period for this behavior. Write "T=_____." Include units.
b. Find the spring constant k for this spring. Write "k=_______." Include units.

Study guide answers:
a. T is about 3.13 seconds (4 cycles completed in 12.5 seconds)
b. In the lab, an equation was given describing the relationship between the period, T, the mass, m, and the spring constant, k. You now have the mass and period, so solve for k. If you use the period of 3.13 s, then k= 0.407 N/m, but answers will vary. For example, T = 3s gives k of 0.443 N/m. Yes, this is a very weak spring as the problem indicated.

<u>Introduction to Computational Analysis</u>

Be able to physically set up the computer interface and use the software to record motion data, and to plot position, velocity, or acceleration vs. time. Be able to use the software to measure and interpret the slopes of lines.

Given a graph of x vs. t, or v vs. t, describe in words what you would have to do to replicate the graph. Make sure that you clearly indicate directions (e.g., "moving away from the sensor" or "moving toward the sensor"), speeds (e.g., "slowly," "quickly") and accelerations (e.g., "constant velocity," "speeding up" or "slowing down").

a. OR, draw a graph (either x-t or v-t) from a description such as "run away from the force sensor, speeding up as you go, then stop for 3 seconds. Turn around and come back, quickly at first and then slowing down. Finally, walk away slowly at constant speed".
b. Make sure you can do this for both x-t and v-t graphs.

<u>Example 1</u>: (You will need a ruler and graph paper for this question. The requested graph is *quantitative*.)

You are using the ultrasonic motion sensor.

Your lab partner is 2.0 meters away from the sensor (point A) and moves away from the sensor while gradually slowing down: that is, she is moving very quickly at first, then continually slowing down.
After 3.5 seconds, she stops at a distance of 6.0 meters from the sensor (point B on your graph), and then immediately moves back toward the sensor at a constant speed of 1.5 m/s.
Finally, when she reaches her original position (point C on your graph), she reverses direction and moves away from the sensor at constant speed of 0.4 m/s, finally stopping when she is 5.0 meters from the sensor (point D on your graph).

Answer: your graph will be quantitative. You have enough information to calculate the times between the various points and to draw the graph described.
Point A is at (0s, 2.0m). It is connected to Point B by a concave down arc.
Point B is at (3.5s, 6.0m). It is connected to Point C by a downward-sloping straight line.
Note she traveled -4.0 m in 2.67 seconds, which is a velocity of -1.5 m/s.
Point C is at (6.17s, 2.0m). It is connected to Point D by an upward-sloping straight line.
Point D is at (13.67s, 5.0 m). Note she traveled 3.0 m in 7.5 seconds, which is 0.4 m/s.

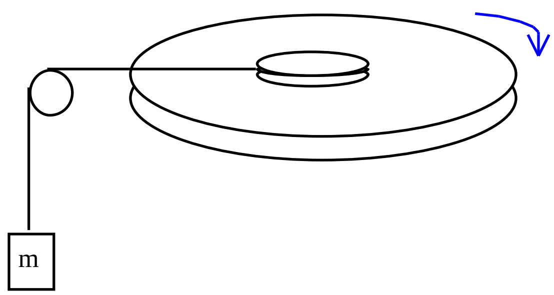
Moment of Inertia of a Disk

Be able to use the rotational dynamics apparatus to measure the moment of inertia of an unknown disk. Or, given data on a disk such as its mass or diameter/radius, and the radius/diameter of a torque pulley, and a table of data (e.g., hanging mass and corresponding angular acceleration, or hanging mass and corresponding linear acceleration), determine the moment of inertia of the disk.

Be able to find the moment of inertia of a disk or annular disk from parameters that you measure (such as mass, inner radius and outer radius).

SAMPLE

A disk of overall diameter 12.6 cm spins on an air cushion, and is connected by a cord to a hanging mass that descends as the disk experiences an angular acceleration. The cord pulls on the disk by unwrapping from a torque pulley of diameter 3.6 cm. The following values are obtained for the hanging mass and the acceleration.



Trial	**Total** mass hanging from cord	Linear Acceleration of falling mass
1	60.0 grams	0.05571 m / sec^2
2	85.0 grams	0.07874 m / sec^2
3	130 grams	0.1199 m / sec^2
4	180 grams	0.1652 m / sec^2

For each of the four trials, calculate the torque exerted on the disk. (Be sure to show your work.) Carefully construct a (**large**) graph of torque vs. angular acceleration, and *from the slope* determine the moment of inertia of the disk. Include units!

(final answer: 0.00340 kg m^2)

Projectile Motion

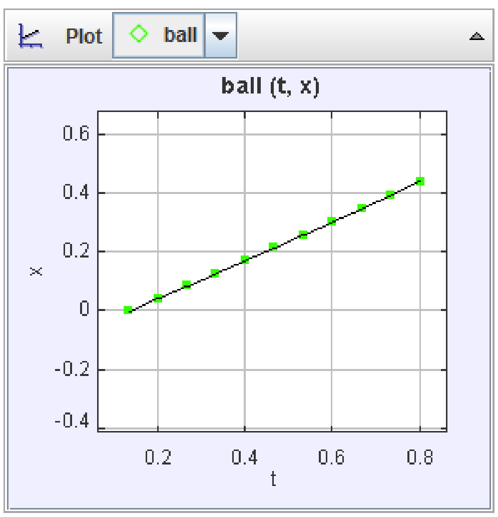
Be able to make graphs of the motion of a projectile, including horizontal and vertical position and velocity graphs.

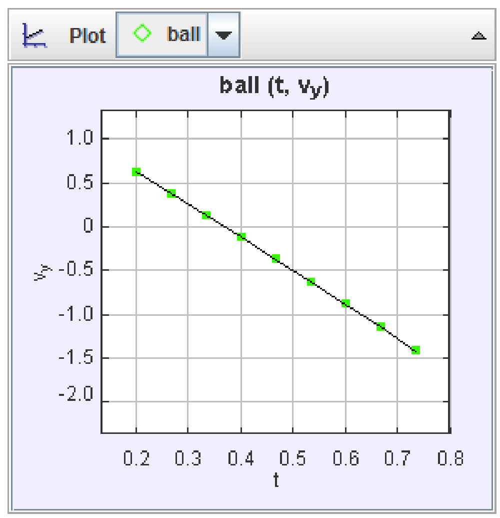
Given graphs of position versus time and/or velocity versus time for a projectile and the fit equations for each, be able to determine the initial position(s)/velocities and accelerations throughout the motion.

SAMPLE

Two graphs of horizontal position-versus-time and vertical velocity-versus-time for a ball in projectile motion on an alien planet are shown below. Also given is the "Fit Equation" for these lines.

Note: The values given are in SI units: distance is in meters, and time in seconds.





Fit Equation
$x = (0.66)t + (-0.09)$

Fit Equation
$vy = (-3.826)t + 1.412$

- What is the initial speed of the ball, i.e, how fast is the ball moving?
  Answer: We find vx and vx at t = 0. It's 0.66 m/s and 1.412 m/s. Use Pythagorean Theorem. 1.6 m/s.
- At what angle from the horizontal is the ball initially moving?
  Answer: Arctangent of initial y-velocity divided by x-velocity. 65°. Makes sense it is initially moving up and to the right. Note that we could find the angle of the velocity at **any** time, not just t = 0.
- What is the vertical acceleration of the ball? Include units.
  Answer: g=3.8 m/s^2 downward *[Remember: The ball is not on Earth.]*
  What is the horizontal acceleration of the ball? Include units. (Zero)

Significant Figures

Example: You are measuring the speed of an object starting at 1.024 m and ending at 2.461 m over a time interval of 1.23 s. What is the average velocity, including the correct number of significant figures? Answer: 1.17 m/s.

Example: Perform the following calculations and round off the answers to the correct number of significant digits. Please report the answer in scientific notation.

1.73 + (0.000533)(92.3)	Answer: 1.78×10^0
$3.141592654 \times 3.2 + 0.6$	Answer: 1.1×10^1
$3.141592654 \times (2.0)^5$	Answer: 1.0×10^2
$3.141592654 \times (29.2)^2$	Answer: 2.68×10^3
(200.9)(69.3)	Answer: 1.39×10^4
200.95 + 1.307	Answer: 2.0226×10^2
(0.000513)(62.3)+1.12	Answer: 1.15×10^0

Remember: The result of addition or subtraction of two numbers has no significant figures beyond the last decimal place where BOTH of the original numbers had significant figures

Remember: The number of significant figures in the result of multiplication or division is no greater than the least number of significant figures in any of the factors

Example A: The floor of a room has dimensions of 23.166 m by 15.7 m. Determine the area of the floor. Report your answer in proper scientific notation, with units and the appropriate number of significant figures. Answer: $3.64 \times 10^2 m^2$

Example B: Masses of 16.16 kg and 1227.6 kg are measured. Determine the total mass. Report your answer in proper scientific notation, with units the appropriate number of significant figures. Answer: $1.2438 \times 10^3 kg$

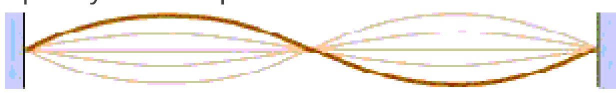
Standing Waves

Given the total string length L, pictures of a few standing wave patterns, and the frequencies at which they are observed, deduce some quantities, given sufficient information. You should be able to graph wavelength vs. period data to find quantities such as the mass per unit length of the string, the tension in the string, or the mass hanging from the end. All graphs that are used to determine a slope must be sufficiently large (at least 1/2 page).

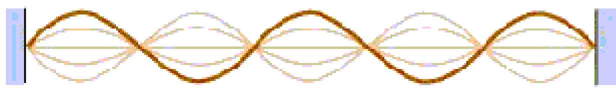
EXAMPLE

A string is stretched horizontally, and one end is connected to the tip of a mechanical oscillator. The other end extends over a pulley and supports a total hanging mass of 300 grams. The string is L = 1.74 meters long, from the point of attachment to the oscillator to the point of contact with the pulley. The patterns shown in the figure (NOT ACTUAL SIZE) are observed at the frequencies indicated.

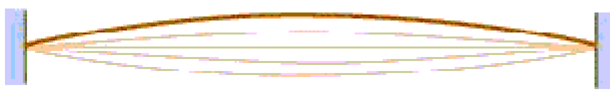
a. Make a (large) graph of wavelength vs. period for the first 3 patterns. Include units on your axes.
b. Using your graph, determine the wave speed on this stretched string? Include units.
c. Estimate the mass per unit length of the string, and please include units!
d. What is the frequency f4 of the pattern shown?



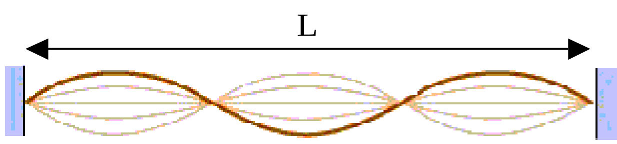
23.6 Hz



59.0 Hz



11.8 Hz



f4 = ??? Hz

Rough solution: from the graph, we find v = 41 m/s.
From the fact that the string supports a hanging mass of 300 grams, we know the string tension is (0.300kg)(9.8 m/s^2)=2.94 newtons.
We know how to relate wave speed, tension, and mass per unit length, so we solve for 1.75e-3 kg/m.
Looking at the pattern, the wavelength λ is 1.16 meters, v is about 41 m/s, solve for frequency of about 35 Hz.

EXAMPLE 2

Suppose you were told the mass per unit length of the string, and its total length, but not the amount of hanging mass. Using the same diagrams as above, you should know how to find the mass, and the tension in the string.

EXAMPLE 3

A string is under a tension of 120.0 N. A 1.600 m length of the string has a mass of 5.700 grams.
a. What is the speed of a transverse wave of wavelength 0.6000 m in this string? (183.5 m/s)
b. What is the frequency of the wave? (305.9 Hz)

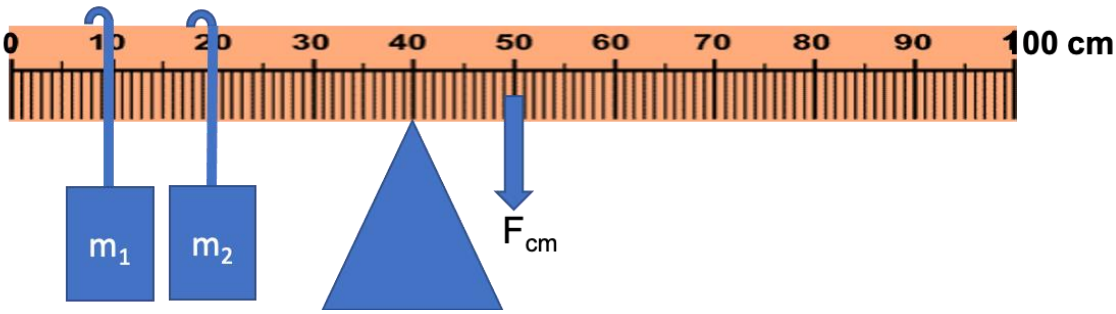
Torque

A meter stick (100cm long) has mass m_s = 100g and is placed on a fulcrum at the 40cm mark.

Masses are attached at the 10 cm mark and the 20 cm mark.

We know the mass m_2 = 30g.

The meter stick is now balanced, in equilibrium, as shown in the figure.



a. In the Torque Lab, you used the sum of the torques around the fulcrum to find an unknown mass. First, you needed to know the distances that would go into the torque sum. Like in the lab, assume that the full torque from gravity acting on the mater stick itself occurs at the 50 cm mark, as shown in the figure. Use the figure to find the three distances of interest here: to the center of the meter stick, to mass 1, and to mass 2.

Write "r_{cm}= _______, r_1= _______, r_2= _______." Include units.

b. Write out the net torque equation, making counterclockwise torques positive, and clockwise torques negative. Set the sum = 0. Write "_____________ = 0" (the application of Newton's second law for rotation to this system). No units needed in this equation.

c. Solve for the unknown mass. Write "m_1 =________." Include units.

Study guide problem final answer: m1 = 13.3 grams.

<u>Vector Addition/Force Table</u>

Given a force table problem with 2 or 3 masses hung at various angles, be able to use the force table, and/or the graphical method, and/or the components method to combine force vectors and deduce any of the following:

a. the *resultant* (i.e., net or total or sum) force
b. the *equilibrant, or balancing,* force (this is NOT the same as net force. Know the difference.)
c. the value and angular location of the *mass* that must be hung to balance the system.

SAMPLE 1

A 150 gram mass (150 g includes the hanger's mass) is hung on a vector force table at an angle of 105°, measured counterclockwise from the zero-degree mark. A second mass of 235 grams (also including the hanger) is hung on the same table at an angle of 180°.

Using **<u>the graphical method</u>** of adding forces, determine the magnitude (include units!) and direction of the *resultant force*. Be sure to clearly label your scale (e.g. the physical distance corresponding to 1 N).

Answer: 3.04 N at an angle of 152°.
Do not mix up the sum and the equilibrant.
Do not mix up the force and the mass.

SAMPLE 2

A 135 gram mass (135 g includes the hanger's mass) is hung on a vector force table at an angle of 115°, measured counterclockwise from the zero-degree mark. A second mass of 310 grams (also including the hanger) is hung on the same table at an angle of 225°.

Using **<u>the components method</u>** of adding forces, determine the amount of *mass* (include units) and its angular location that will balance the center ring.

Answer: 293 grams at an angle of 19.3°.
Do not mix up the sum and the equilibrant.
Do not mix up the force and the mass.