Studio Physics

Engineering Physics I

PHYS 213
Department of Physics
Kansas State University
Fall 2010

Studio Physics Laboratory Demos and Numerical Problems

Success in physics is based on three elements: conceptual understanding, problem solving skills, and the concepts of measurement. Studio Physics has been created to integrate these three elements. It consists of you, your fellow students with whom you will interact, the instructors and a series of specially created laboratory Demos and accompanying numerical problems. Each of the laboratory Demos has been created to give tangible example to what may be considered standard problems in fundamental physics. These problems contain key concepts that reside at the core of physics. By solving problems and then experimenting with the real thing, the conceptual foundation of the problem will grow by example along with problem solving abilities. Moreover, quantitative measurement will, through experimental uncertainty, teach realistic expectations. Once exact agreement is deemphasized, the trends and functionalities will appear and conceptual understanding can again grow.

Your tasks for Studio Physics are straightforward. Problems for situations similar to these lab Demos will be given as the assignment for that day's work. These are best done the night before the Studio class. Many problems, which relate directly to the lab Demos, are included in this book. Your studio instructor may also assign some of these problems as in-studio group activities. Next, the lab Demo should be performed, measurements made and trends in the data discerned. Numerical results and trends should be compared to the calculation.

Many of the laboratory Demos ask questions or suggest data manipulation procedures. These should be used as guides for further insight into the physics of the situation. Very important to this enterprise is your interaction with your lab partners to discuss the physics and procedures of the Demo. With your peers, teach and be taught.

Integral to your studio experience is your lab notebook. Record your data and observations on what happened (right or wrong). Make graphs and straightforward conclusions, answer and perhaps pose questions. Keep it spontaneous and simple! A notebook is for notes, not refined dissertations.

Lastly, as you work on physics, remember to integrate as you learn the three basic elements of conceptual understanding, problem solving, and an appreciation how numbers can describe the physical world.

Acknowledgments: The creation of these laboratory Demos owes a great deal to Alice Churukian, William Hageman, Chris Long, Farhad Maleki, Corrie Musgrave and Jason Quigg. More recently, Peter Nelson, Dr. Kirsten Hogg, Dr. Rebecca Lindell and Professor C.L. Cocke have made valuable suggestions. This manual was edited with minor revisions in the spring of 2004 by Kevin Knabe, and in the spring of 2005 by Danny Kaminsky. Dave Van Domelen has also contributed with minor revisions. This work was supported by a grant from NSF (CCLI) to Susan Maleki and Chris Sorensen.

Chris Sorensen
University Distinguished Professor

Guidelines for Lab Notebooks in Studio

Observation is the essence of science, and controlled observation is experimentation. A Dutch proverb says elegantly: "Meten is Weten" which translates to: "measuring is knowing." When you perform your lab work in Studio, controlled observation to measure and thereby know will be emphasized.

Integral to this experimental process is a written record of your experimental work. Your Lab Notebook is a working, written record of experimental work. It should contain sufficient information so someone else can understand what you did, why you did it and your conclusions. Also, pragmatically, it is inevitable that the assessment of your experimental work in the Studio is largely based upon it.

The following is an outline of the expectations we have for the records you will keep in your Lab Notebooks.

Description of Experimental Work

1. The date should be recorded at the beginning of each session in the studio.
2. Each experimental topic should be given a descriptive heading.
3. A BRIEF introduction describing the purpose of the experiment, description of apparatus and experimental procedures should be included.
4. Schematic or block (rather than pictorial) diagrams should be included where appropriate.
5. Circuit diagrams should be included.

Records of Observations and Data

1. The lab notebook must contain the original record of all observations and data – including mistakes! Never erase 'incorrect' readings; simply cross them out in such a way that they can be read if need be. There is no such thing as bad data.
2. All relevant non-numerical observations should be clearly described. A sketch should be used whenever it would aid the description.
3. The nature of each reading should be identified by name or *defined* symbol, together with its numerical value and unit.

Tables

1. Observations and data should be gathered and tabulated whenever appropriate.
2. Each table should have an identifying caption.
3. Columns in tables should be labeled with the names or symbols for both the variable and the units in which it is measured. All symbols should be defined.

Graphs

1. With graphs we often discover functionalities. Don't hesitate to graph your data or numerical results if you think it will help you see what's going on, even if it is not your "final," concluding result.
2. Graphs should be drawn directly into your lab notebook.
3. Each graph should have a descriptive caption. Axes of graphs should be labeled with the name or symbol for the quantity and its unit. Numerical values should be written along each axis.

Analysis and Results

1. The organization of calculations should be sufficiently clear for mistakes (if any) to be easily found.
2. Results should be given with an estimate of their uncertainty whenever possible. The type or nature of each uncertainty should be specified unambiguously.
3. Results should be compared, whenever possible, with accepted values or with theoretical predictions.
4. Serious discrepancies in results should be examined and every effort made to locate the reason.

Summary/Conclusions

1. A BRIEF summary should be written for each experiment.
2. The summary should report the results and contain a comparison with accepted values or with theoretical predictions. Any discrepancies should be mentioned.

Table of Contents

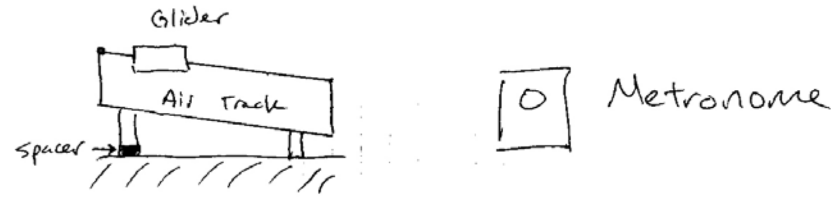
The following three pages are an example of a good lab that contains everything that is required out of a lab.

01/20/04

[2-1] Accelerated Motion

x from t and quadratic functionality

[Intro] Today we will determine how x and t are related when an object is under constant acceleration. We will use the air track, a glider, and a metronome.

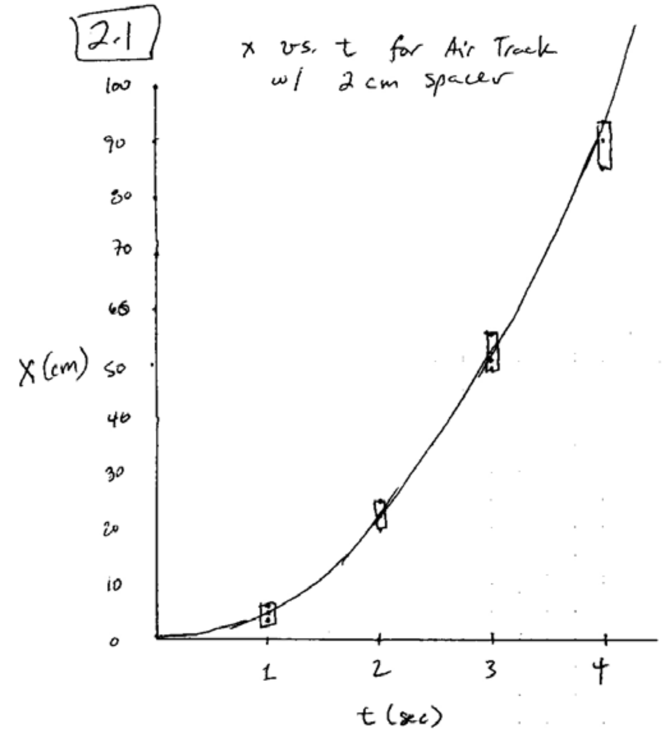


[DATA/ANALYSIS] Metronome will beat once a second, and our group will observe the distance traveled from the start and record this.

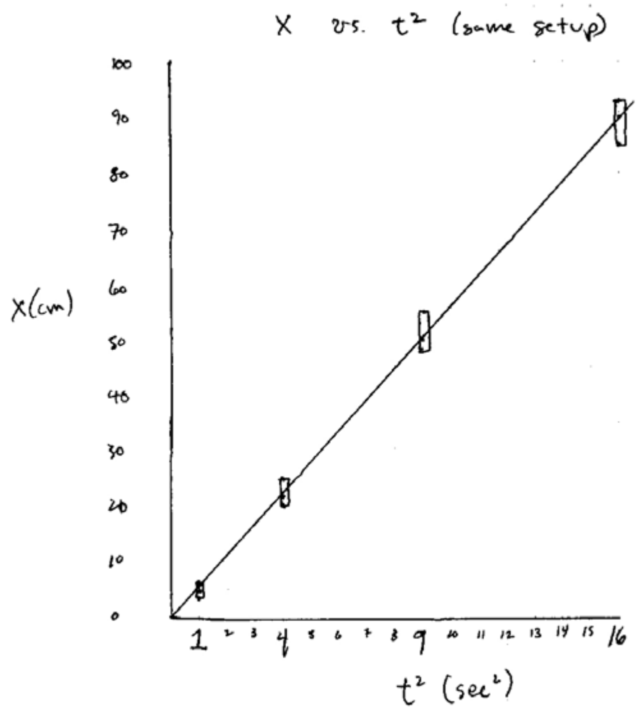
	time (sec)	0	1	2	3	4
Trial 1	x (cm)	10	15	32	60	100
	Δx	0	5	~~85~~ 22	50	90
Trial 2	x	10	16	35	65	103
	Δx	0	6	25	~~45~~ 55	93
Trial 3	x	10	14	30	58	95
	Δx	0	4	20	48	85

Table of positions for given time on an Air Track with one end elevated by 2cm

2.1



* Best fit curve looks like a parabola!



→ Best fit line proves

$x = m t^2$

$(y = mx + b)$

slope $= \frac{\Delta y}{\Delta x} = \frac{85}{15}$

$=$ ~~60~~ cm/s²

$= 5.7$ cm/s²

2.1 We know that from chapter 2 that

$$x = \frac{1}{2} a t^2$$

and by analysis of the graph of x vs. t^2,

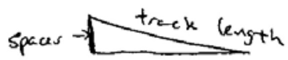
$$x = m t^2 \quad \text{where } m = 5.7 \text{ cm/s}^2$$

By comparison, $m = \frac{1}{2} a$. So $a = 2m = 11.4 \text{ cm/s}^2$

→ Make an educated guess on how the acceleration depends on the slope.

The acceleration probably depends on either the sine or cosine function. This is because the air track makes an angle with the table. We notice that our acceleration is small, so we should choose the function that is small when our angle of inclination is small. This function is sine.

$$\sin\theta = \frac{\text{spacer distance}}{\text{track length}} = \frac{2 \text{ cm}}{180 \text{ cm}} = \frac{1}{90}$$



$$a = g \cdot \sin\theta = 9.8 \frac{m}{s^2} \times \frac{1}{90} = 0.109 \frac{m}{s^2} = 10.9 \frac{cm}{s^2}$$

calculated: $10.9 \frac{cm}{s^2}$

experimental: $11.4 \frac{cm}{s^2}$

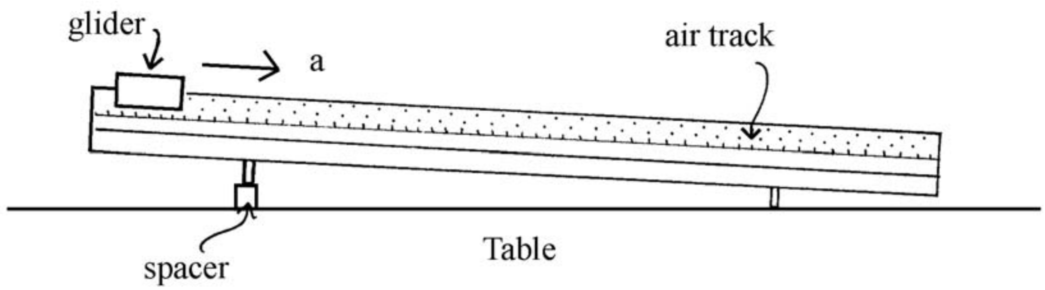
Very close! (~ 5% error)

Conclusion: This lab worked very well. Our calculated and experimental acceleration matched up with very little error. Through this we proved the functionality of x vs. t^2. The error we had in this lab could be attributed to physical measurements (eyesight, reaction time, hearing metronome).

2.1. Accelerated Motion, x from t and Quadratic Functionality

Lab Demo

Level the air track. Now incline the air track by placing a spacer 1/2 to 2 cm thick under one of the feet. Place the glider at the high end of the air track and note its position. One person, the starter, can hold it there, while two others, the observers, sit close to the air track at two positions down the track. Set the metronome pulsing. Coincident with a given pulse, the starter releases the glider. At the next pulse of the metronome, the first observer notes the position of the glider as it passes. The second observer does the same at the second pulse. Record positions and times and repeat a few times to get an estimate of your experimental uncertainty.



- Let x be the distance traveled in a certain time t. Graph the data x vs. t. Is x a linear function of t?
- Graph the data x vs. t^2 (this is accomplished by squaring all the time values, and plotting the according distances). Is x a quadratic function of t? Include (x,t)=(0,0) on each graph.
- Use your data to find the acceleration.
- Repeat for a different incline (i.e., slope) and compare accelerations. Make an "educated guess" on how the acceleration depends on the slope. Do the data support your guess? Can you find a relation between the acceleration on the incline, g=9.8 m/s^2, and the slope?

2.2. Accelerated Motion, t from x

Lab Demo

Level the air track and then put a 1 cm spacer under one of the feet. Hold the glider at rest, then let it go. Use a stop watch to:

- Determine how long it takes to go a distance d (about 0.75 meter).
- Determine how long it takes to go 2d.
- Did it take twice as long? How is t related to x?

2.3. Acceleration of Gravity

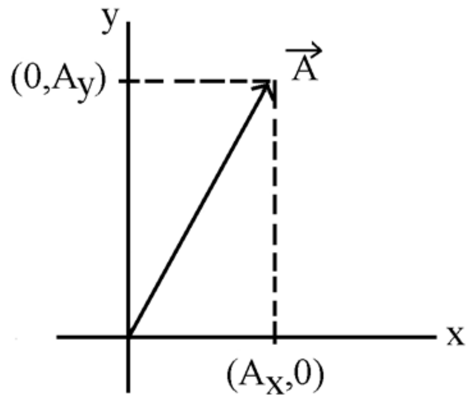
Lab Demo

Mount the spark timer above the edge of the table about 1.5 meters above the floor. Attach a mass (20g to 100g) to the tape. Thread the tape through the spark timer. To reduce friction as the mass falls, it may be necessary to gently hold the free end of the tape above the spark timer. Turn on the spark timer with a frequency of 60 Hz and drop the mass.

- Look for the spark spots on the tape. Label every 5^{th} spot, "0" for the initial spot, "1" for the fifth spot after the mass was released, “2” for the tenth, etc.
- Note how the spacing between the spots increases with time even though the time interval is the same. How would the spots be spaced if the speed was constant? Measure the distances from the "0" spot to the other spots. With these distances and the known time interval, calculate the acceleration.
- If a different mass is used, would the acceleration be the same or different? Test your contention like a scientist--do an experiment.

3.1. Vector Addition

Lab Demo



Use a ruler to construct a coordinate system and then draw an arbitrary vector $\vec{A}$ on the large format graph paper. Make sure to leave enough room for all four quadrants. Put the tail of the vector on the origin.

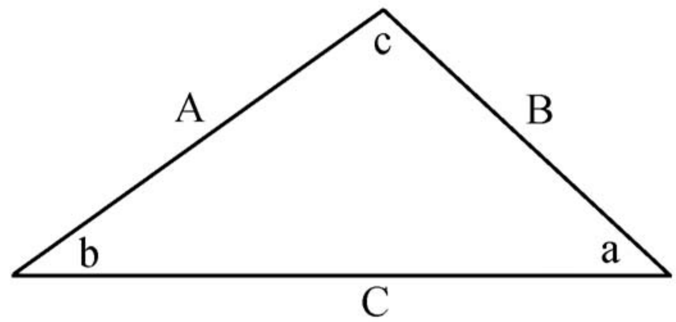
- Find the coordinates of the head of the vector. What are the x and y components of the vector, A_x and A_y?
- Measure the length and the angle, from the x-axis, of the vector. Calculate the components using trigonometry and compare to those measured above.
- Draw a second vector $\vec{B}$, different than $\vec{A}$. Find its components.
- Add components of vectors $\vec{A}$ and $\vec{B}$ to find the components of $\vec{C}$ where $\vec{C} = \vec{A} + \vec{B}$. Plot $\vec{C}$.
- Now graphically add $\vec{A} + \vec{B}$ and compare to the component addition.
- Repeat for $\vec{D} = \vec{A} - \vec{B}$.

3.2. Triangles

Lab Demo

Draw an arbitrary triangle using a ruler.

- Measure its side lengths, A, B and C.
- Measure its angles a, b, and c.
- Verify numerically the law of sines and the law of cosines.



3.3. Vector Dot Product

Lab Demo

Return to 3.1 and vectors $\vec{A}$ and $\vec{B}$. Find $A \cdot B = A_x B_x + A_y B_y$ numerically with the components previously measured. From this calculate $\cos\theta$, where θ is the angle between $\vec{A}$ and $\vec{B}$. Now measure θ and compare.

3.4. Vector Cross Product

Lab Demo

Return to 3.1 and vectors $\vec{A}$ and $\vec{B}$. Find the vector $\vec{E}$ such that $\vec{E} = \vec{A} \text{ x } \vec{B}$ with the formula $E = AB \sin\theta$, and the right hand rule. The vector $\vec{E}$ is perpendicular to what plane?

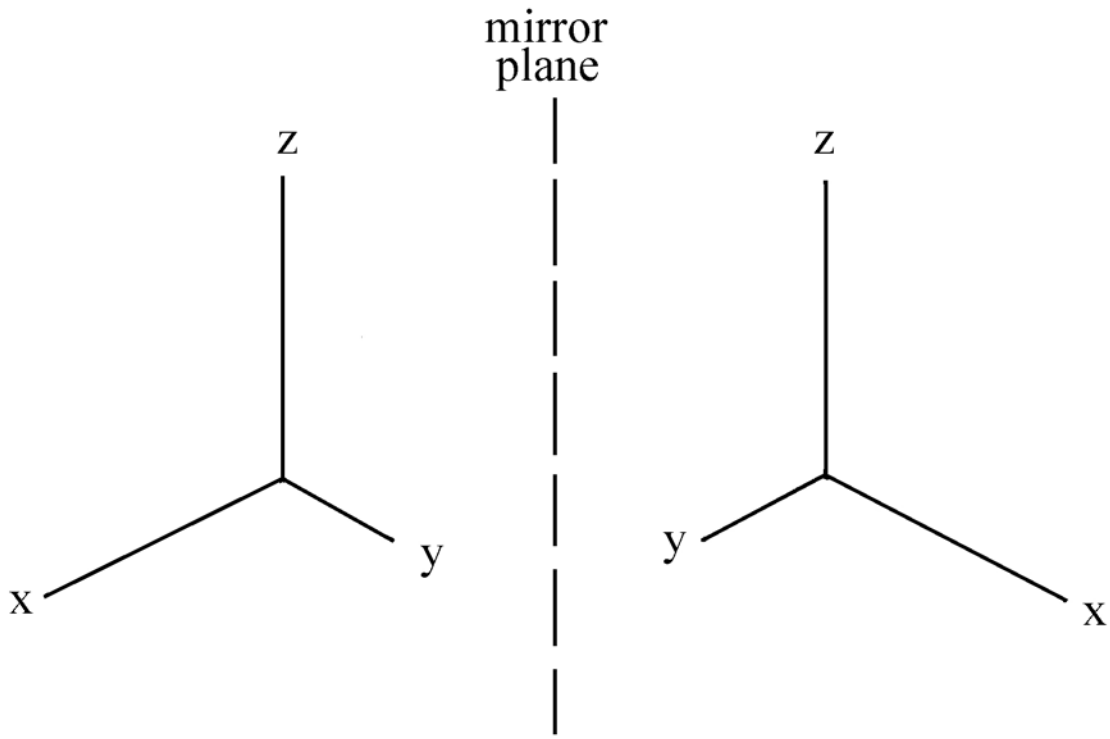
- Find $\vec{F} = \vec{B} \text{ x } \vec{A}$ and compare to $\vec{E} = \vec{A} \text{ x } \vec{B}$. Does the cross product commute?

3.5. Right and Left Hand Rules

Lab Demo

Mess around with the right hand and left hand screws provided.

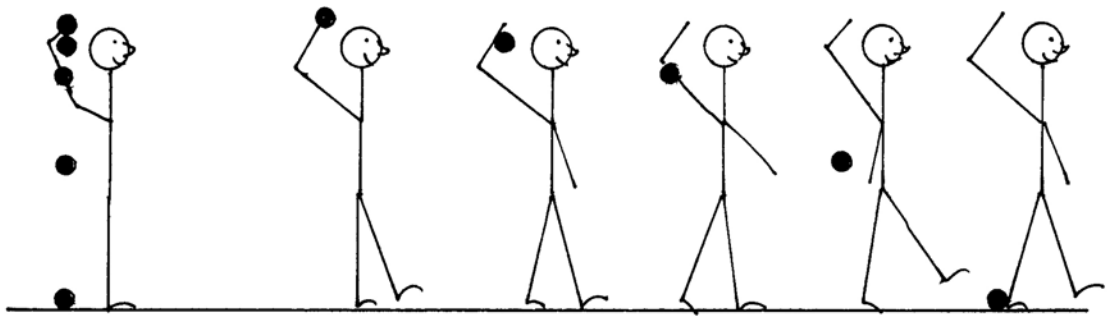
- Use the right hand and left hand rules to determine the direction of travel of the screw (or nut on the screw).
- Compare the mirror images of the screws, motions, and hands.



4.1. Independence of X and Y

Lab Demo

Hold a ball at about head height and drop it. It bounces straight back up along your body. Catch it. If you now walk with constant velocity and drop the ball, how will it fall and bounce relative to your body after you drop it? Does your motion in the x-direction affect the ball's falling in the y-direction? Do an experiment to find out.



4.2. Projectile Motion-Graphical

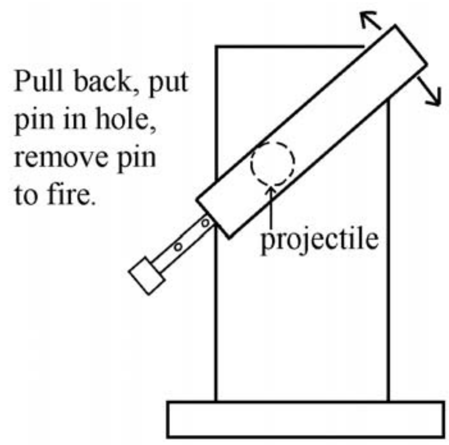
Lab Demo

Consider a projectile motion problem provided by your instructor with an initial velocity (magnitude and direction). Write an expression for the position vector $\vec{r}(t)$. (This is the Equation of Motion.) Let the acceleration of gravity be $\vec{g} = 9.8\text{m}/\text{s}^2$, down. Graph $\vec{r}(t)$ for various t values on large format graph paper (use the same scale for the x and y directions; also, do not make your scale until you have calculated various values of t). Find $\vec{v}(t)$ and plot it on the trajectory of $\vec{r}(t)$. Pay attention to the components of $\vec{v}(t)$. Plot the velocity at integer times (i.e. 0s, 1s, 2s…). When plotting velocity, let your vectors be 1.0 cm long for every 10.0m/s of velocity.

- Now let g=0 and plot the position vector for the same times as you did for when, $g = 9.8\text{m}/\text{s}^2$, down. Call this vector $\vec{r}_o(t)$. Physically, what is $\vec{r}_o(t) - r(t)$?

4.3. Projectile Motion

Lab Demo



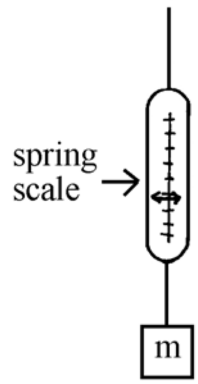
Set the projectile launcher with the barrel vertical. Shoot the projectile ball straight up and measure how high it goes. From this calculate the initial velocity, v_o. Try this for different spring compressions Δx (preferably on the "medium" setting). Plot a graph of v_o versus spring compression. How does v_o vary with compression (linear, quadratic, exponential...)?

- Now aim the launcher at an arbitrary angle, e.g., 45°. Measure the angle and the muzzle height above the surface where the ball will hit and calculate the horizontal range using v_o from above. Shoot the ball, measure the range and compare. Be aware that hitting the floor changes both your x and y values!
- Aim the launcher horizontally. From the height of the muzzle above the tables or floor, calculate the flight time. With v_o from above, calculate how far the ball will go.
- The agreement between experiment and theory will not be good when $\theta = 0$ and the spring is highly compressed. Why? You may not be able to answer this now, but later, when we study energy, we will find out why.

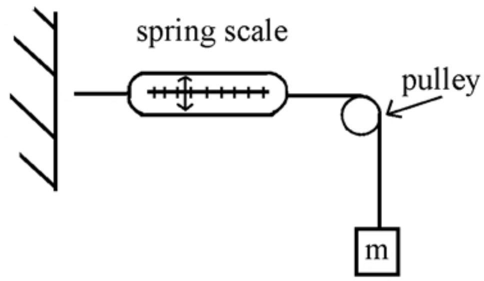
5.1. Static Forces

Lab Demo

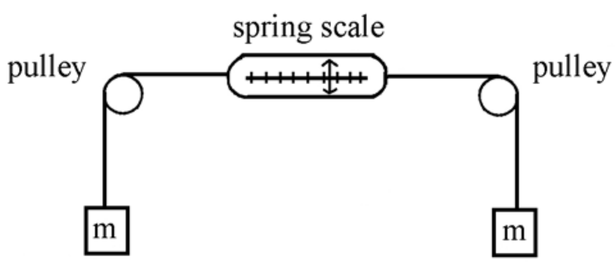
Connect a string to a spring scale and then to a mass (m=1 to 5kg, much larger than the scale), as drawn. What tension in the string is indicated by the scale?



- Now run the string over a pulley and attach the scale to a support, as drawn. Now what is the tension?



- Now take two equal masses, hang them by strings over pulleys and place the spring scale horizontally between the two, as drawn. What is the tension?

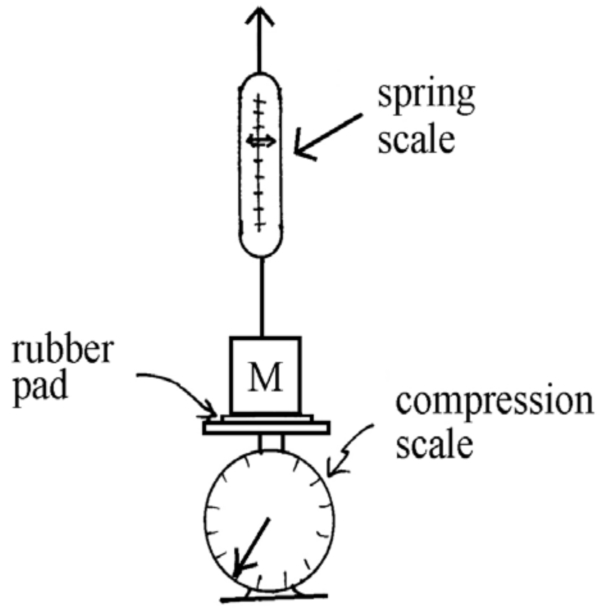


- Now put a second spring scale in the arrangement (anywhere). What do the scales read?

5.2. The Normal Force

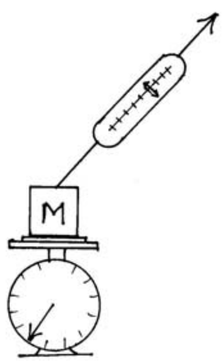
Lab Demo

Place a small rubber pad (for friction) on a compression scale. Place a mass (e.g., m=0.5 kg) on the scale. The scale is now measuring the normal force N on the mass. Remember to report the values using significant figures – these scales are not extremely accurate!



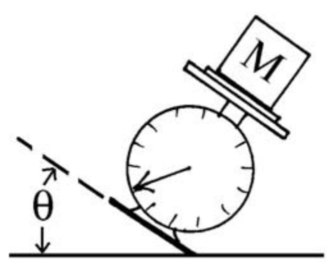
- Take a spring scale and pull vertically upward (see drawing). Record the normal force (on the compression scale) for different upward forces and make sense of the relationship between the upward pull, the reading on the compression scale and the force of gravity.

- Now pull with the spring scale at different angles (15˚, 30˚, 45˚) from the vertical. Again compare the normal and pulling forces and make sense of their relationship.



- Now tip the scale so that the platform is at an angle θ from the horizontal. The scale is still reading the normal force (normal to what?). Find the relationship between N, mg and θ.

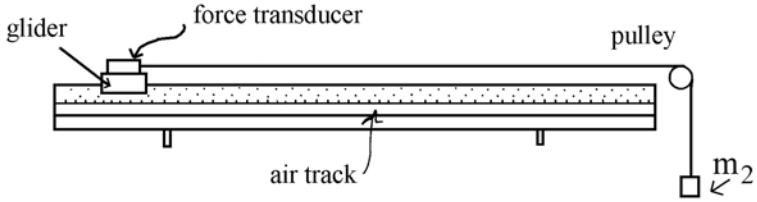
- Finally hold the spring scale in your hands in front of you with a mass on it. Qualitatitively, what is the normal force when you accelerate the scale up or down; when you move it at constant velocity up or down?



5.3. Two-Body Accelerated Motion

Lab Demo

Set up and level the air track. Put a glider on it and on the glider put the force probe and some mass so that the total mass, call it m_1, is much larger than m_2. Attach a string to the transducer part of the force probe and run it over a pulley at the end of the track (and table) to another mass, $m_2 \simeq 0.1\,\mathrm{kg}$.



- Hold the glider stationary and measure the tension in the string. What is this due to?
- Let the glider go (with the air track operating) and measure the tension in the string during the motion. Why is it less than the tension when stationary?
- Measure the distance m_2 falls and the time to fall and hence its acceleration. This can be done in Data Studio.
- Calculate the tension and acceleration for the two-body system and compare to the measurements.

5.4. The Bosun's Chair

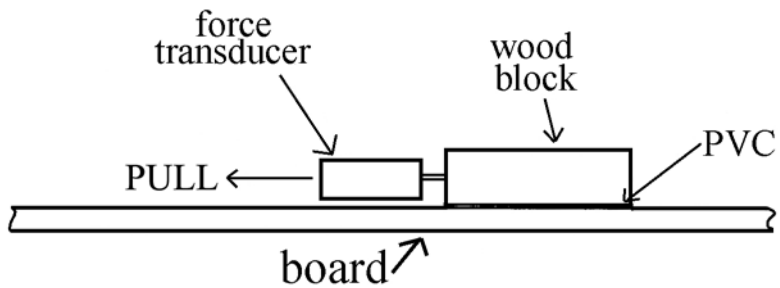
Lab Demo

Support yourself in the Bosun's chair by holding the rope in your hand. Note the tension in the rope. Next tie off the rope to an external support or have a strong, and heavier, friend hold it. What is the tension now? Show the force diagram and explain.

6.1. Static and Kinetic Friction--On the Level

Lab Demo

Set up the computer system with the force transducer so that force can be measured as a function of time. Place the block of wood with PVC on one side on the inclined plane board, PVC side down, level on the table. Pull the mass with the force transducer by hand, starting with little effort but continuously increasing your effort over a few seconds until the mass slips and then for another second or two with the mass slipping. This experiment works best when conducted slowly.

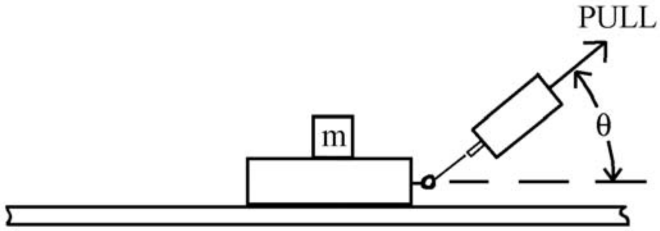


- Examine the recorded trace of the force as a function of time and make sense of it relative to the concepts of static and kinetic friction.
- Calculate the friction coefficients μ_s and μ_k .
- Redo with different mass stacked on the original mass and find how friction depends on the normal force.
- Would a horizontal push yield different results from the pull?

6.2. Static and Kinetic Friction--Inclined Pull

Lab Demo

Use the same block and plane (still level) as in 6.1. Pull on the block with the force transducer at an angle θ above horizontal (say 30 or 45 or 60°). Both measure and calculate, from the μ of 6.1, the pull force where it begins to slide. Don't forget to include a force diagram.

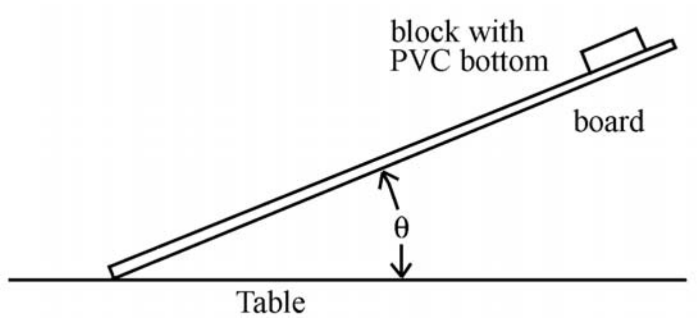


6.3. Angle of Slip

Lab Demo

Use the same block and same plane as in 6.1. Put the mass near one end of the board and slowly lift that end.

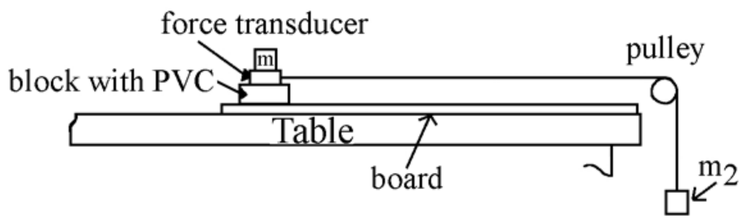
- Measure the angle when the mass begins to slip and from this calculate μ_s. Compare to 6.1.
- Do this with more mass stacked on the block. Does the mass matter?
- What is the frictional force when the angle is less than the maximum value and the block is not moving?



6.4. Two-Body Accelerated Motion with Friction

Lab Demo

Use the same block and plane as in 6.1. Put the force transducer on the block along with some mass for a total mass of $m_1 \simeq 1.0\,\text{kg}$. Attach a string to the transducer, run the string over a pulley to $m_2 \gtrsim 0.5\,\text{kg}$ hanging above the floor.

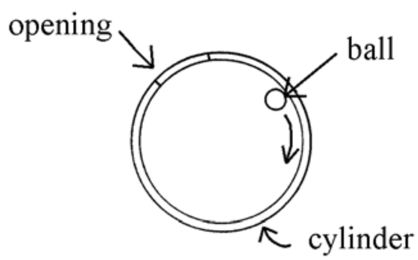


- Hold m_1 stationary and measure the tension in the string. What is the tension due to?
- Let the mass go. Measure the tension while in motion and compare to the static tension.
- Measure the distance m_2 falls and the time to fall and hence its acceleration.
- Calculate the tension and acceleration for the two-body system and compare to the measurement.

6.5. Circular Motion

Lab Demo

Put the small ball inside the metal cylinder on the table. Give the ball a push tangentially along the inner surface of the cylinder. The ball travels in circular motion. What force must exist for this circular motion? What is the agent causing the centripetal force? What happens when the ball comes to an opening in the cylinder wall? Does the ball fly straight out, directly away from the center? Be sure to sketch the path you observe.

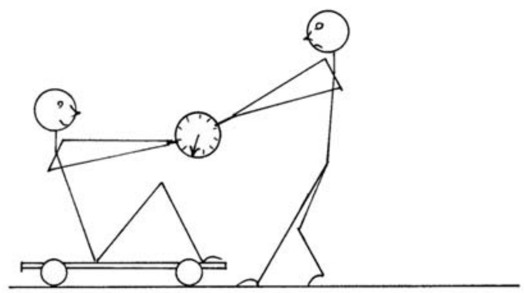


7.1. Work and Kinetic Energy

Lab Demo

Determine the mass of a person plus a roller cart. Have this person sit on the cart with her/his feet on the floor to hold it stationary. Mark a path in front of the cart 2 or 3 meters long. A second person stands in front of the cart with a large spring scale. The person on the cart holds on to the other end of the scale. The standing person pulls until a force of about 50 to 100 N is applied to the stationary cart/person system. Now the person on the cart lifts his/her feet to allow the cart to move. The pulling person continues to pull the 2 to 3 meters at a constant force as indicated by the scale, and then stops pulling as soon as the prescribed distance is traversed. The sonic ranger pointed at the back of the person/cart system measures the velocity.

- Calculate the work done by the puller and the kinetic energy of the person/cart system and thereby test the work-energy theorem. Yes, there is considerable experimental error, but you can still test the work-energy theorem within the uncertainty of the measurement (approximately how much energy would be lost to friction?).

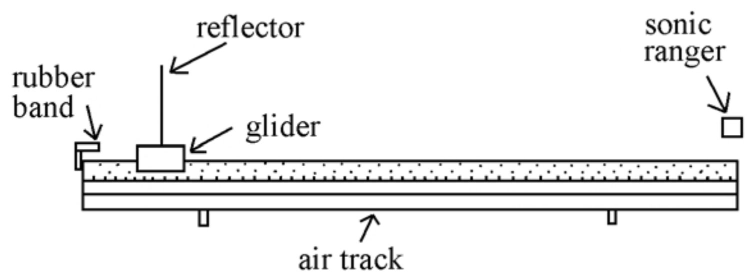


7.2. Spring Potential to Kinetic Energy

Lab Demo

Set up the air track level. Adjust the glider to have a mass in the range 0.1 to 0.3kg. Stretch a rubber band across the bumper at the end of the track.

- Measure the force constant of the rubber band in this stretched configuration.
- Compress the rubber band a distance x. Place the glider against it. Put a sonic ranger at the other end of the air track to measure the velocity as the glider approaches it. The glider may need a reflector. Release the glider (i.e., shoot the glider) and measure its velocity. Vary x and m. Graph v vs. x for various m. Calculate the work done by the rubber band, which acts like a spring as it pushes the glider a distance x. From this calculate the velocity of the glider and compare to experiment.

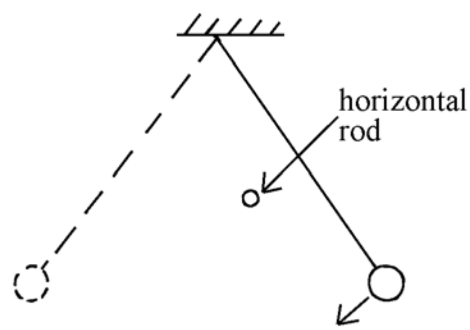


8.1. Path Independence

Lab Demo

Set up a pendulum with a string (0.8 to 1.0m long) and a mass (m ~0.5 kg).

- Pull the pendulum to the side, with the string taut, and measure the mass's height above the table. Let the mass go and measure how high it gets when it comes to a momentary stop at the other side of its swing. Compare heights.
- Repeat but place a fixed, horizontal rod in the path of the string as drawn. Measure how high it goes now and compare.

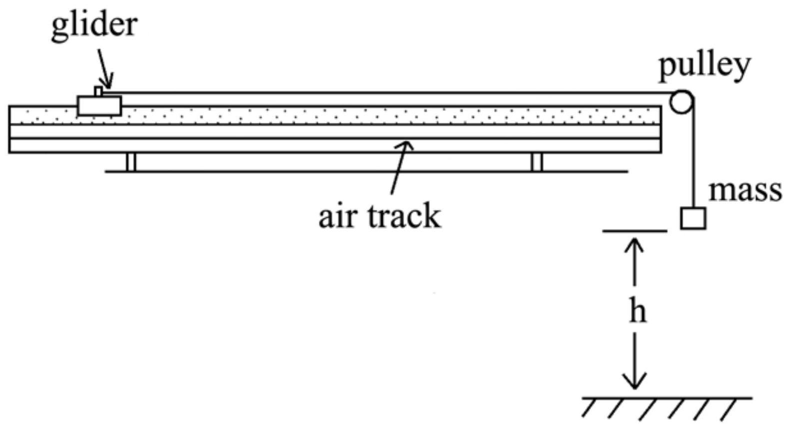


8.2. Gravitational Potential to Kinetic Energy

Lab Demo

Adjust the air track so it is horizontal and put a glider on it. Attach a string to the glider, run this over a smart pulley and then attach a mass to the other end of the string (see drawing). Masses on the order of 0.1 to 0.3 kg will work well.

- Drop the hanging mass a measured distance h. Measure the velocity on impact with the floor with the smart pulley. Compare this to calculation.



8.3. Spring, Gravitational and Kinetic Energies

Lab Demo

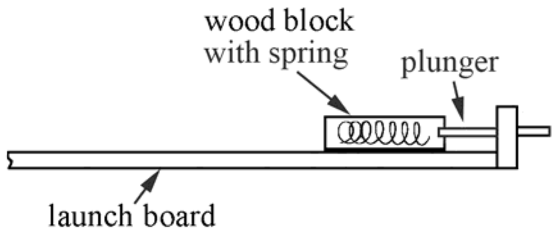
- Return to the projectile launcher of 4.3. Once again shoot it vertically and determine the maximum height of the projectile as a function of the compression. (Make sure you get the zero of compression correct.) Plot h(max) vs. Δx. Are they linearly related? Is there a better way to plot this? What combination of h(max) and Δx should be a constant?
- Measure the spring constant of the spring in the launcher. Measure the mass of the projectile. Calculate the h(max) for a given Δx and compare to the measurements.
- Determine the muzzle velocity of the ball when the launch is either vertical or horizontal. They are not the same. Shoot the projectile horizontally, measure and calculate the range and compare. Also compare to your original results in 4.3.

8.4. Dissipation of Mechanical Energy by Friction

Lab Demo

Mount the wooden block with spring on the launch board.

- Measure the force constant of this spring, k.
- With the plane level, compress the spring a distance x, place the block (mass m) against plunger, release the block. Measure the distance, d, the block goes along the plane before it comes to rest.



- Vary x and check the functionality, i.e., plot d as a function of x and find a way to make these graphs linear (as an example, recall that for accelerated motion a graph of x vs. t^2 is linear.)

9.1. Center of Mass

Lab Demo

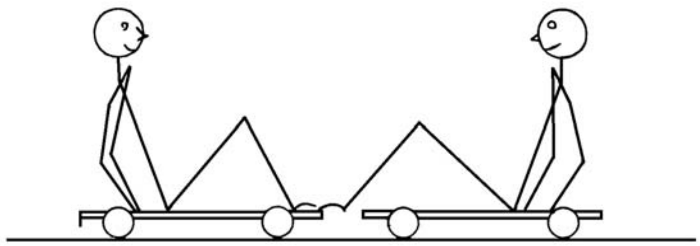
Calculate the position of the center of mass for the geometrical objects given. Try both the standard method (i.e. break up a complex geometry into a sum of simpler geometries) and the method of negative mass (ask your instructor!). Determine the center of mass experimentally (how?) and compare. Do not draw directly on the objects. If your experimental method requires doing so, tape a piece of paper to the objects instead.

9.2. Center of Mass and Internal Forces

Lab Demo

Have two people sit on two roller carts facing each other. Set up sonic rangers behind them to measure their velocities. Measure the mass of each person plus cart. Have one or both people (does it matter?) push away from the other. Measure and calculate their velocities immediately after the push.

- Measure the position of the center of mass before the push and after carts come to rest.

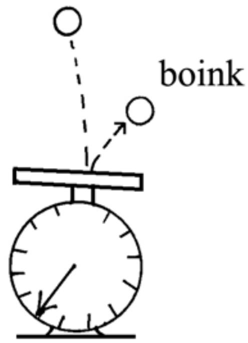


10.1. Momentum Change and Impulse

Lab Demo

Drop a live ball onto a scale from a given height. Notice the maximum scale deflection (be fast!). Drop a dead ball (of the same mass) from the same height. Compare the deflection.

- Which ball yields the greatest impact? Which ball was the greatest change in momentum?



10.2. Linear Elastic Collisions

Lab Demo

With the air track, perform a number of elastic collisions. What is always conserved in a collision? What may or may not be conserved (depends on if it is elastic or inelastic)?

- Let $m_1 = m_2$, $v_1 \neq 0$, $v_2 = 0$. Keep in mind for a 1D, elastic collision the relative velocity of approach equals the relative velocity of recession.
- $m_1 > m_2$, $v_1 \neq 0$, $v_2 = 0$
- $m_1 < m_2$, $v_1 \neq 0$, $v_2 = 0$

  For each collision measure the final velocities, calculate them, compare theory and experiment.

10.3. Linear Inelastic Collisions

Lab Demo

Repeat 10.2, only for inelastic collisions. With the air track, perform a number of inelastic collisions. What is always conserved in a collision? What may or may not be conserved (depends on if it is elastic or inelastic)?

- Let $m_1 = m_2$, $v_1 \neq 0$, $v_2 = 0$.
- $m_1 > m_2$, $v_1 \neq 0$, $v_2 = 0$
- $m_1 < m_2$, $v_1 \neq 0$, $v_2 = 0$

For each collision measure the final velocities, calculate them, compare theory and experiment.

10.4. Linear Elastic Collisions and Relative Motion

Lab Demo

Hold a basketball with a tennis ball directly above it and nearly touching. Drop them together. Why does the tennis ball rebound so quickly? To answer this, approximate the bounces (collisions) as elastic, use what you should know about relative velocities in a 1D (i.e., linear) collision and the fact that the basketball is much more massive.

10.5. Newton's Cradle

Lab Demo

This device usually has five equal mass, hard steel balls each supported by two strings so the balls can swing only in one direction. At rest, all five balls are in a line, touching.

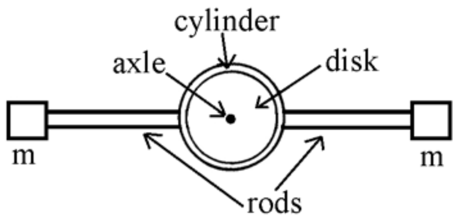
- Pull the end ball to the side and release it. What is the result of the ensuing collision? Explain using the physics of collisions (1D, elastic, same mass).
- Pull two balls on an end to the side together and release them. What happens and why?
- Pull to the side three balls, four balls. What happens, why?

11.1. Rotational Inertia

Lab Demo

Find the rotational inertia I (aka, the moment of inertia) of the "rotational inertia apparatus" about its axle, a sketch of which is drawn below. This is a composite body consisting of a cylinder, disk, a rod and two point (nearly) masses.

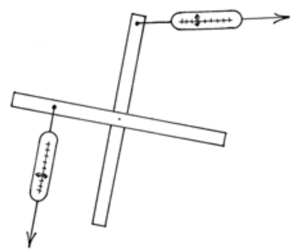
- Which of these parts dominates the total I? Why? What is most important, mass or location relative to the axle?
- Given your results, how might you approximate I for this apparatus?



11.2. Torque

Lab Demo

Set up the torque apparatus. Connect spring scales at various positions and pull. Show for various r, F and angles that if the apparatus is static, the total torque is zero.

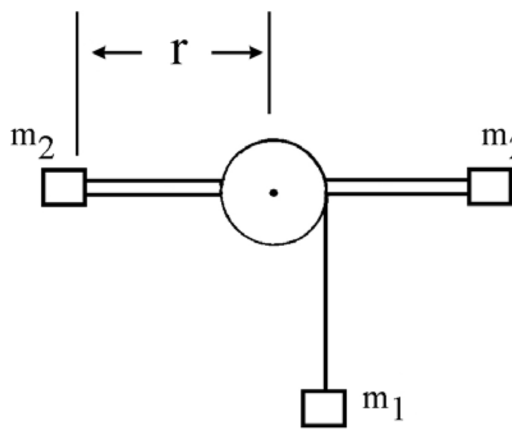


11.3. Acceleration in a Translation/Rotation System

Lab Demo

Set up the rotational inertia apparatus about 1.5 m above the floor. Hang a mass m_1 from the rotational inertia apparatus. Use your calculations from 11.1 to approximate the inertia of the apparatus.

- Place the masses m_2 at $r \simeq 20$ cm and balanced. Measure the time for m_1 to fall a given distance. Pick m_1 so that the time to fall is a few to several seconds (why so long?). From this determine the linear acceleration of m_1.



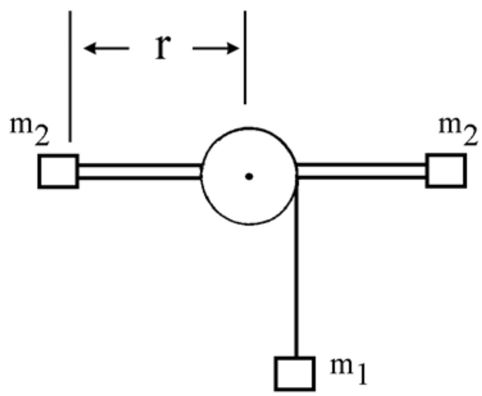
- Use mechanics to calculate the linear acceleration of m_1 and compare to your measurement.
- Now move the masses m_2 to half the r above and repeat. What do you think the new time of fall will be? Measure it and find out.

11.4. Energy Conservation in a Translation/Rotation System

Lab Demo

Set up the rotational inertia apparatus about 1.5 m above the floor. Put its two masses at the ends of the rods, balanced. Hang a mass $m_1 \simeq 0.2\,\text{kg}$ on a string from the rotational inertia apparatus.

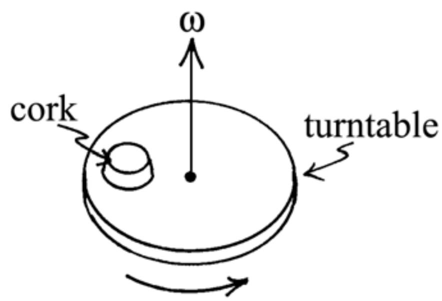
- Calculate the rotational inertia assuming it is due only to the two masses on the ends of the rods. Why does this approximation work (recall 11.1)?
- Measure the time it takes for m_1 to fall a distance h~1.5m to the fall.
- Using energy principles calculate the time it takes m_1 to fall to the floor and compare to measured values.



11.5. Friction Causing a Centripetal Force

Lab Demo

Set the turntable rotating and control its angular speed by the variable switch. Measure its angular speed either by using a stop watch or by using the computer. Set the angular speed to about 1 rev/sec. Place the cork (wide end down) close to the axis of rotation so that the cork does not slip. What are the forces acting on the cork? Draw a free-body diagram for the cork. Now move the cork slowly outward from the axis of rotation and note the distance from the axis of rotation where it first starts slipping. Find the coefficient of static friction μ_s between the cork and the material of the turntable from your measurements. Do you need to measure the mass of the cork to compute μ_s?

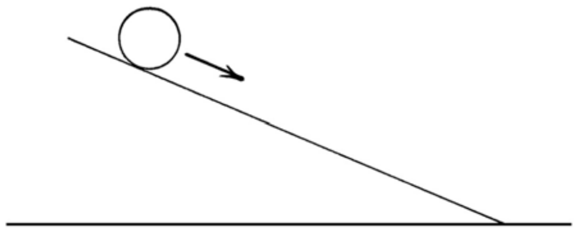


12.1. Rolling

Lab Demo

Race different sized and shaped objects down an inclined plane. Use disks, hoops and spheres. Experimentally determine the functionality of time to travel a given distance from rest on mass, radius, and shape.

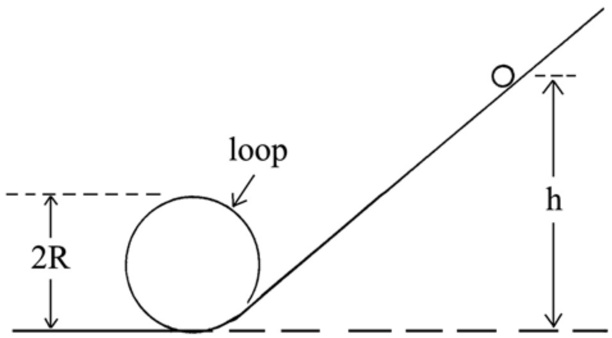
- Quantitatively calculate the time for a rolling object to travel from rest down an inclined plane and compare to the measured time.



12.2. Rolling and Circular Motion

Lab Demo

Determine experimentally the minimum height to start a ball (solid sphere) from rest so that it will travel around the loop without leaving the track. Compare this to theory.



12.3. Conservation of Angular Momentum - I

Lab Demo

- Sit on the rotating stool and spin yourself. Vary the extent of your arms and legs and note your rotation. What changes; what stays the same? Hold on to weights to accentuate this phenomenon.
- While sitting on the stool, throw something side-arm; catch something to the side. Is angular momentum conserved? How are angular and linear momentum related?
- Now repeat this semiquantitatively. Sit on the stool, throw a massive (~1kg) object side-arm. Measure the distance from the axis the thrown object was when thrown, estimate its velocity. Estimate your rotational inertia. Calculate your recoil angular speed and compare to your actual speed.

12.4. Conservation of Angular Momentum - II

Lab Demo

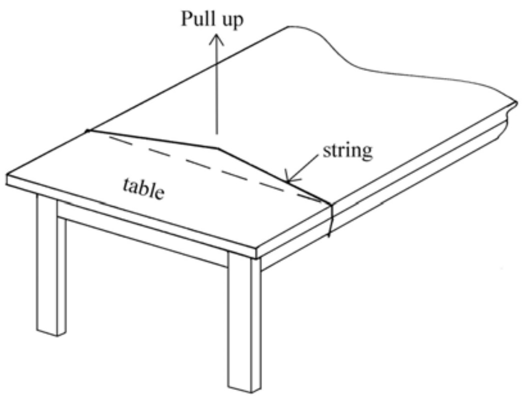
Set the weighted wheel rotating while holding each side of the axle.

- Try to rotate the plane of the wheel. What happens? Explain the direction of recoil.
- Sit on the rotating stool and change the plane of the weighted wheel. Explain what happens.
- Set the rapidly spinning weighted wheel on the floor like a top. Why doesn't it fall? Why does it precess? Turn the wheel over (i.e., put the other axle on the floor). What happens? Why?

13.1. Statics of a Point

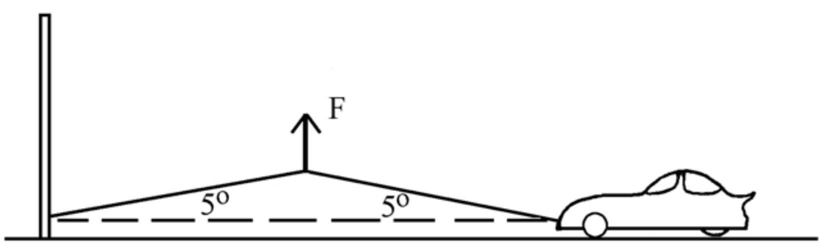
Lab Demo

Get some string that is hard to break by hand pulling. Wrap it once <u>tightly</u> around the lab table and tie it with a square knot. Pull up on the string near the middle of the table. Can you break it now? Explain.



Now try to recreate the "Car Stuck in the Mud" problem.

- Attach a piece of string to a "tree" (a stationary object that won't move, like a table leg), and attack the other end to the "car" (an object that takes considerable force to drag along the floor).
- Make sure the rope is tight , and measure how much force in needed to pull the rope sideways and get the car "unstuck."
- Now compare this to the amount of force needed to directly pull the car out of the mud by yourself.
- Move the 'car' back to its starting position when you are done.

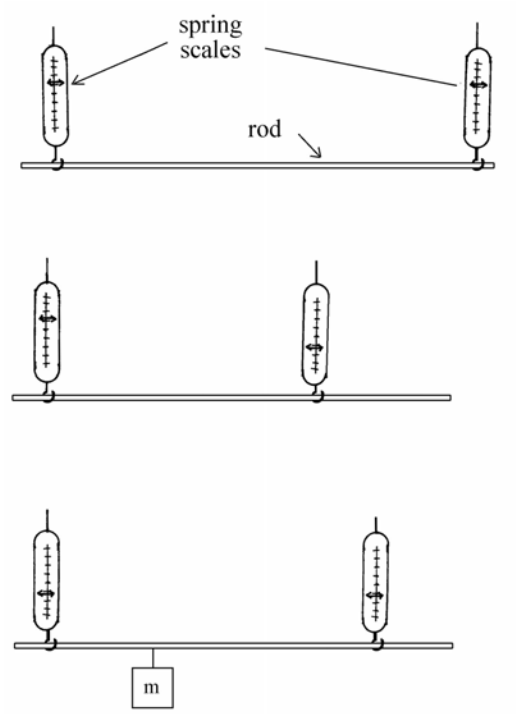


13.2. Statics of an Extended Object

Lab Demo

Hang a long rod over the lab table with a spring scale at each end. Keep the scales vertical.

- Determine the mass of the rod with these scales. What does symmetry imply about the force measured by each scale?
- Now break the symmetry and vary the position of where the spring scales are connected to the rod. Then measure and calculate the forces in the spring scales.
- Place another mass on the rod at various positions x (see drawing), measure and calculate the forces in the spring scales. What is the sum of the vertical spring scale forces equal to?

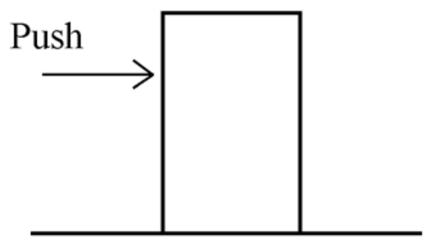


13.3. Tipping Versus Sliding

Lab Demo

Set a large wood block on its end on the table.

- Use the force transducer to determine the static coefficient of friction by pushing on the block near the bottom. This engenders the question: how high up the block can one push it and not have it tip over before it slides, i.e., what is the maximum height before it tips over?
- Determine this maximum height both experimentally and theoretically and compare. Does this height depend on the mass of the box, its width, or its height?

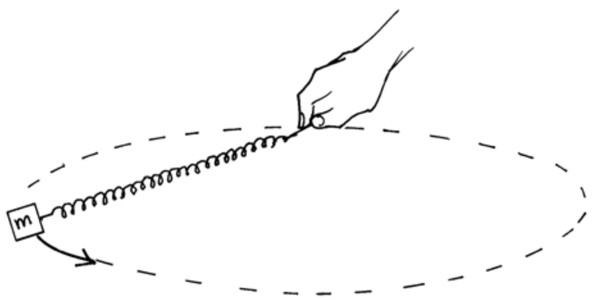


14.1. Orbital Motion with a Spring

Lab Demo

Use a short spring that stretches to several times its unstretched length. Attach a mass at one end and hold it at the other. By hand motion set the mass in orbital motion around your hand in a horizontal plane. Measure as well as you can the orbital period T and radius R. Vary T and R with your hand motion.

- What is Kepler's 3rd Law for this type of orbital motion, i.e., what is the functionality of T with R?
- Calculate T and compare.



14.2. "Weightless"

Lab Demo

- Hang a mass on a spring scale and note its weight. Stand on a chair or table, holding the scale which is weighing the mass. Jump off to the floor and note the weight during your fall.
- Put some water in a paper cup. Poke a pencil hole in the cup and water will flow out of the hole. Drop the cup and watch the hole while the cup is falling.

14.3. Simulated Orbital Motion

Lab Demo

Under development!

15.1. Density

Lab Demo

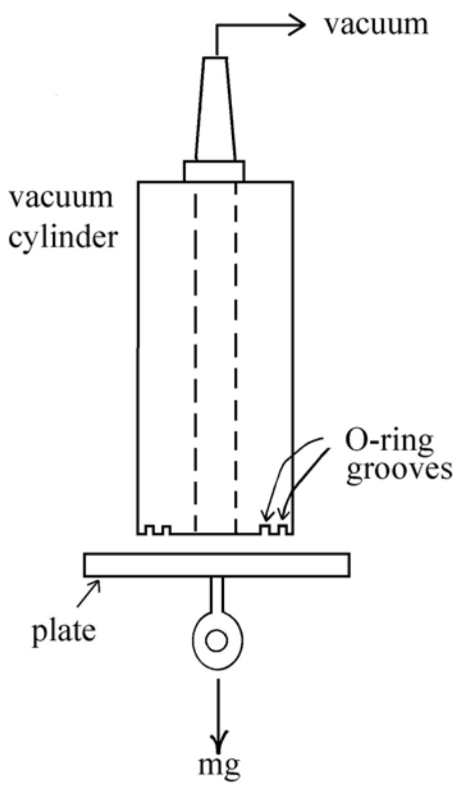
Compare by hand the masses of 2 inch cubes of various materials. What are their relative densities?

15.2. Atmospheric Pressure

Lab Demo

Mount the metal vacuum cylinder on a ring stand. Using a hand pump pull a "vacuum" on the metal cylinder with the metal plate held against and underneath it. Make sure there is an O-ring in one of the grooves on the cylinder.

- Hang masses on the plate until the plate falls from the cylinder and record this mass (some leakage may occur so have someone continue pumping). Make sure someone is prepared to catch the masses when they fall.
- Repeat for an O-ring in the other groove. Compare the diameters of the O-rings and the masses that pulled the plate off the vacuum cylinder.
- Calculate the atmospheric pressure assuming the vacuum in the cylinder is good. Actually, the hand pumps aren't perfect so assume atmospheric pressure is $10^5\ \mathrm{N/m^2}$ and determine the actual pressure in the cylinder when pumped down? Does the vacuum suck? Which way does the pressure push?

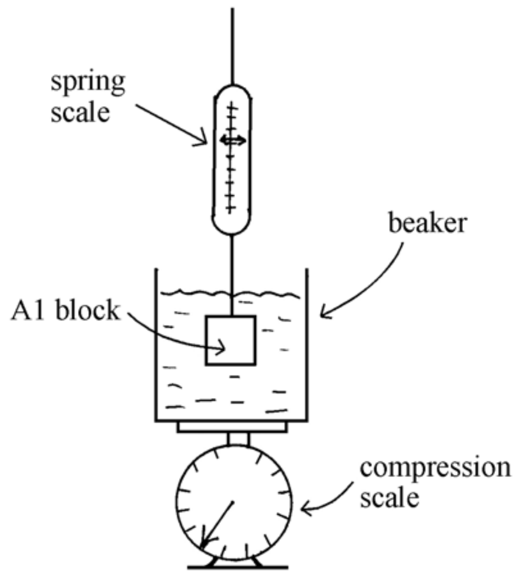


15.3. The Bouyant Force – Archimedes' Principle

Lab Demo

Use a spring scale to determine the weight of a block of aluminum. Fill a 1000ml beaker with about 500 ml of H_2O. Note the exact volume with the graduations on the beaker. Be sure to have a supply of paper towels on hand.

- Lower the block of A1 which is on the spring scale until completely submerged in the water. What is the weight of the A1 block in the water? What is the buoyant force on the block?
- Note the level of the water in the beaker when the A1 block is submerged. How much water was displaced? From this calculate the buoyant force and compare.
- Now place the beaker on a compression scale. Note its weight. Once again lower the A1 block into the water. What is the apparent weight of the beaker and the water? Why?



15.4. Floating

Lab Demo

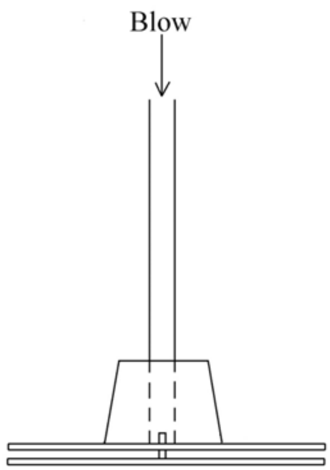
Fill a 1000ml beaker about half full of water and place it on the compression scale. Note both the total weight and the level of the water.

- Put a block of wood in the water and let it float. With the new reading on the compression scale, what is the weight of the wood?
- Record the new level of the water. How much water was displaced by the floating wood? What is its weight? What is the buoyant force? How does it compare to the weight of the wood?

15.5. The Bernoulli Effect – I

Lab Demo

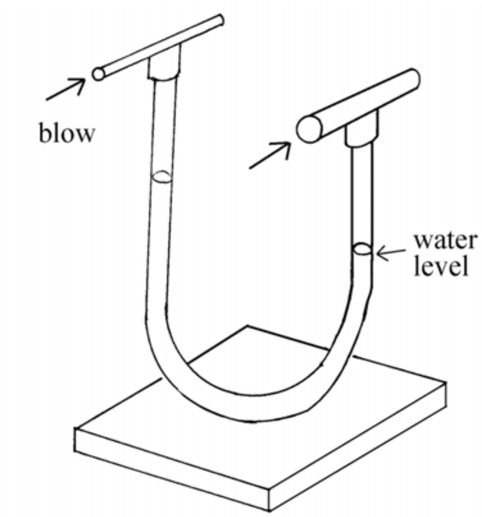
Blow into the "Bernoulli apparatus" drawn below and see what happens. What “force” is causing this to happen?



15.6. The Bernoulli Effect - II

Lab Demo

Show that a pressure differential can be developed across the U-tube in the apparatus drawn below. The different sides have different diameters. Does this make a difference? Does the direction of the air flow matter? Test and explain.



16.1. Spring-Mass Oscillations

Lab Demo

- Determine the force constant k of your springs by hanging various masses on them and measuring the displacement. This is best done by plotting F vs. x.
- Hang a mass m on the spring, set it oscillating and measure its period T. Change the amplitude and determine the functionality of T with the amplitude.
- Vary the mass and determine the functionality of T with m. How might you best plot your data to achieve a linear graph?
- What are the frequencies of the motion above?
- Try a spring with a different force constant.

16.2. The Simple Pendulum

Lab Demo

Hang a mass m from a string of length ℓ.

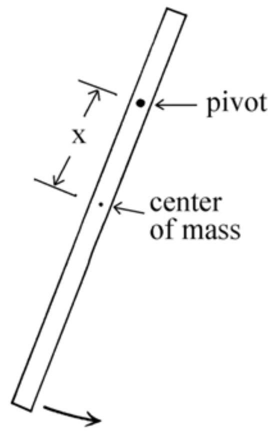
- Set it oscillating and determine the functionality of the period T with mass, length ℓ and amplitude. How might you plot T vs. ℓ to achieve a linear graph?
- From your measurements and theory, determine g.

16.3. The Physical Pendulum

Lab Demo

Hang a meter stick on a pivot through a hole near one end of the stick.

- Measure and calculate the period. Is this equivalent to a simple pendulum with all the mass at the meter stick's center of mass?
- Now vary the position of the pivot along the stick and measure the period T. Plot T vs. x, where x is the distance from the center of mass to the pivot.

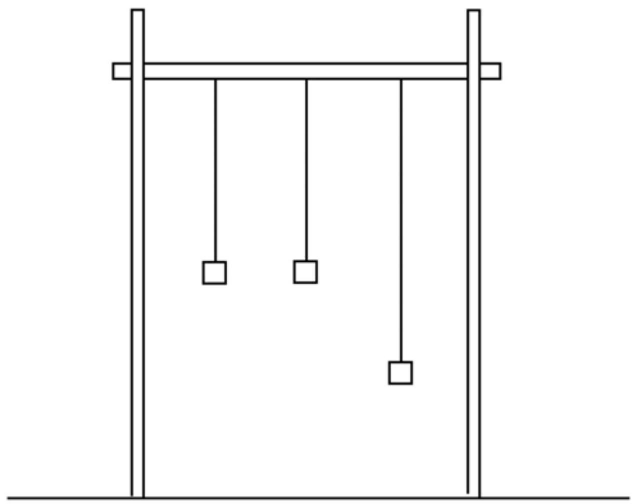


16.4. Resonance

Lab Demo

Set up two vertical rods and a horizontal rod as drawn. Use 3/8" rod material. Suspend three pendula of different lengths from the horizontal rod, each with ca. 0.5kg masses.

- Set one oscillating and note the behavior of the other two for a period of 20 to 30 sec.
- Adjust the length of one until it matches the length of another. Now set one of these same length pendula oscillating and observe the motions of the other pendula for the next minute or so.

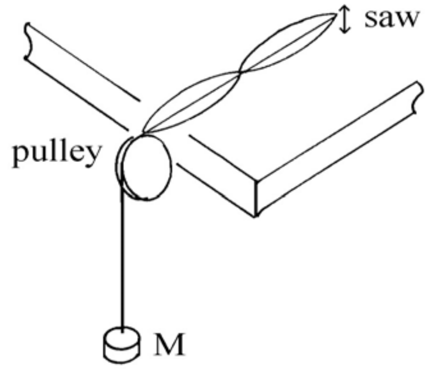


17.1. Waves on a String

Lab Demo

Wiggle the elastic rope and excite various oscillations. Note that some oscillations require very little effort to keep them going. These are called standing wave resonances. Excite the fundamental. Excite as many overtones as you can. How are the modes distributed along the rope (the "cavity" of the oscillator)?

17.2. Standing Waves on a String



Lab Demo

Set up the saber saw wave generator with an attached string which runs over a pulley to a mass of ~0.1 to 0.2 kg. This mass provides a tension in the string.

- Turn on the wave generator (saw) and move it toward and away from the pulley looking for resonances, i.e., standing waves of maximum amplitude. Find the fundamental and a few harmonics. Measure the length of the string in each resonance. Why do these lengths have a common divisor? What is the wavelength of the standing waves? Estimate the frequency (make an approximation comparing the fastest frequency at maximum power to the power you are operating at) and find the wave velocity and the linear mass density of the string.
- Vary significantly the mass causing the tension and find the new wavelength. Empirical determine the functionality of λ vs. m and then compare to theory.
- Set the string length (i.e., the "cavity" length) to some intermediate value (e.g., near the 3rd harmonic). Gently pull down on or lift up on the hanging mass thereby varying the string tension, hence the wave velocity, hence the wave length, and find various resonances.
- Think about what determines the frequency, speed, and wavelength of the waves.

17.3. Standing Waves in a Hanging Chain

Lab Demo

This demo is very qualitative. Hold a light chain about a meter long by one end above the floor. Move your hand holding the chain periodically back and forth in the horizontal direction. Notice how if you move at just the right frequency, the chain will resonate with your motion and develops a large amplitude oscillation even with very little hand movement. Where are the nodes and antinodes of this resonances? What are the boundary conditions? What are the wavelength, frequency and wave speed?

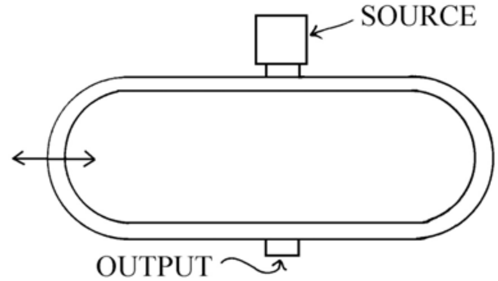
- Move your holding hand at a slightly lower frequency. What happens to the amplitude of the oscillation?
- Move your holding hand at higher frequencies until another resonance is obtained (sometimes a slight rotational motion works best). Where are the nodes and antinodes? What are the boundary conditions? What are the wavelength, frequency and wavespeed and compare these to the fundamental resonance above.
- Continue for higher harmonics.

18.1. Interference of Sound Waves

Lab Demo

Set up the acoustical interferometer and tune the input sound frequency to f~1000Hz. Place your ear next to the open, output end of the interferometer and listen to the sound intensity as you slide the tubing back and forth. Measure how much the slide moves between successive maxima and minima in observed intensity.

- From this calculate the sound wavelength.
- Then calculate the speed of sound.



18.2. Beats

Lab Demo

Use two tuning forks. Excite one and listen carefully. Excite the other and listen carefully while both oscillate. Do you hear a beat? You may not if they are closely matched in frequency.

- Add some mass to the end of one fork by putting a rubber band on the end. Now excite both forks and listen carefully for a beat. Repeat for more or less mass and explain the changes.
- Use the microphone and the oscilloscope display of the computer. Excite one fork and hold it near the microphone. Adjust the trace speed until a nice sine wave is seen. Determine the frequency of the fork.
- Now slow the trace speed to ~100 msec/div. Excite both forks (for which you have heard beats) and explain the trace you see.
- This analysis of the beat phenomenon can also be observed by using two interferometers and setting them a couple of Hertz apart.

18.3. The Doppler Effect

Lab Demo

Excite a tuning fork. Wave it away and towards your ear (or the ear's of others). Explain what you hear.

19.1. Thermal Expansion

Lab Demo

Play around with the relative sizes of the rings and balls as they are expanded and contracted with temperature.

19.2. Mechanical Equivalent of Heat

Lab Demo

Fill a small thermos half full with water. Allow it to come to thermal equilibrium and measure its temperature precisely ($\pm$ 0.1^{o}C).

- Put the lid on the thermos tightly and shake it vigorously 400 to 500 times. Now measure the temperature; what do you find?
- Do a rough calculation of the amount of mechanical energy that was dissipated to heat. Calculate the temperature rise and compare to that measured above.

19.3. Coexistence Temperature

Lab Demo

Fill the small thermos about half full with room temperature water. Add some ice (ca. 50 grams), and shake the thermos until thermal equilibrium is obtained (10-20 sec). If the ice is completely melted, add a little more until a small amount remains after equilibration.

- Measure the temperature of the system and explain its value.
- If you now add more ice, will the system get colder? Try it (remember to shake it for thermal equilibrium) and see.

19.4. Heat Capacity

Lab Demo

Determine the mass of the small aluminum block. Put the same mass of room temperature water in the small thermos. Measure its temperature. Put the A1 block in a hot water bath with $T \simeq 100^oC$. Measure the temperature of the bath and let the block sit in the bath ca. 5 min. to equilibrate to this temperature.

- Then place the hot block into the water in the thermos.
- You have equal amounts (masses) of A1 and H_2O. If you knew nothing of heat capacities, what might you expect the equilibrium temperature to be?
- If you now know the specific heat of water is nearly five times greater than that of A1, how could you qualitatively improve your naive expectation above?
- Calculate quantitatively, measure, and compare the equilibrium temperature.

19.5. Latent Heat

Lab Demo

Place 150 g of room temperature water in the small thermos and after equilibration measure its temperature. Next add 20 gr of ice. The ice may be wet with its liquid so try to strain or wring this away before weighing and adding to the liquid. Shake or stir the thermos until thermal equilibrium is achieved (how can you experimentally verify that thermal equilibrium is achieved?)

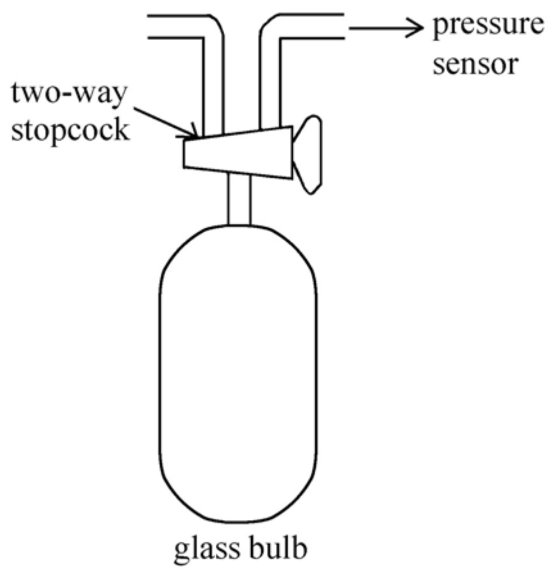
- Measure the equilibrium temperature and compare to calculation. What assumptions do you make?

20.1. Ideal Gas--Gay Lussac's Law (p vs. T)

Lab Demo

Measure the volume of the glass bulb. Connect the bulb to the pressure sensor.

- Place the bulb in hot water and measure both the temperature T and the pressure p at equilibrium (equilibrium determined how?).
- Repeat for ice water.
- Repeat for liquid nitrogen.
- Graph p vs. T.
- From p, T, the measured V and what you know about moles find the ideal gas constant, R.
- Is there a temperature where $p \rightarrow 0$? According to your data where does this happen?

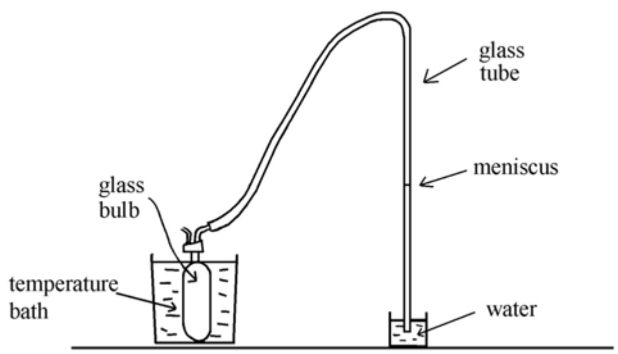


20.2. Ideal Gas—Charles's Law (V vs. T)

Lab Demo

Measure the volume of the glass bulb. Attach flexible tubing from the bulb to a piece of glass (or plastic) tubing ca. 1 meter long and 0.6 cm inside diameter. Measure this tube's inside diameter. Set up the tubing so it is vertical and arrange for a beaker of water to be placed under its open end (see drawing). Place the bulb in a beaker of hot water (at least 40°C) measure the temperature of the water and wait until the system comes to equilibrium (determined how?).

- Now move the bulb to room temperature water, and then ice water, with equilibrium established at each. Measure the temperatures and the height h of the water meniscus in the tube as the contracting gas sucks up the water. (Oops! Can gases suck?)
- From these data calculate the change in volume with temperature. Plot the total volume (make an approximation, what is the volume of air in the tube compared to the volume of the bulb) as a function of T. Is there a temperature at which $V \rightarrow 0$. According to your data, where would this happen?



20.3. Equipartition of Energy and Brownian Motion

Lab Demo

In 1872, Robert Brown, a distinguished British botanist, while observing grains in a watery medium, noticed the erratic movements of the grains that was not attributable to any reasonable cause.

Subsequently Gouy in 1888, Einstein in 1905, and Perrin in 1913 established that the Brownian motion was caused by the random collisions of molecules with the particles and hence finally established (after 2000 years) the atomic nature of matter and the kinetic theory of heat and molecular motion.

The Brownian Scope is a device for conveniently viewing Brownian motion. It is a hand-held 200 power microscope which is fitted with a smoke sample chamber, a glare stop, and a spherical dark field condensing lens.

Operation:

1. Light a match and let it burn a bit and then blow it out.
2. Holding the smoke chamber with the open end down, allow the resultant smoke to enter the chamber.
3. While the smoke chamber is still inverted, put the Brownian scope back together.
4. Turn the device over and point it toward a strong light source and look in the scope.

If you wear glasses, you should remove them.

Since the Brownian scope has dark field illumination, the smoke particles will appear as bright spots on a gray or black background.

20.4. Adiabatic Compression or Expansion

Lab Demo

In this demonstration you will rapidly push a plunger down into a clear cylinder at the bottom of which is a small amount of easily combustible material, e.g., cotton. The rapid compression will be adiabatic because it will be much faster (~milliseconds) than the time it takes for the heat to get out. Where does the heat energy come from?

To do this, place the bottom end of the cylinder firmly and vertically on the table. Strike the plunger forcefully and quickly with the palm of your hand, straight down. Care must be taken because these devices can break. During the strike, have your lab mates watch the combustible material. If done well, it will ignite. To redo, or if cotton does not ignite, air out the cylinder and repeat the procedure. Estimate the compression ratio from careful observation of a strike. From this calculate the maximum temperature due to the compression.