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.

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Professor

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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.

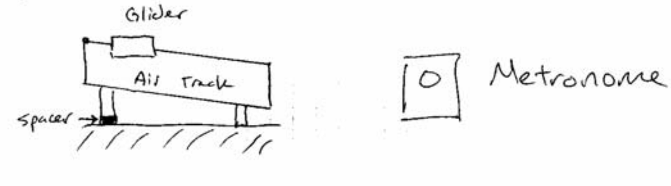
Table of Contents

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

01/20/04

$\boxed{2.1}$ Accelerated Motion
x from t and quadratic functionality

$\boxed{\text{Intro}}$ 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.

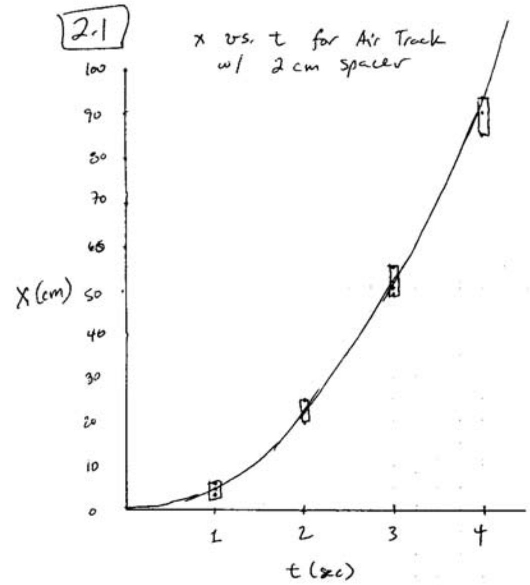


$\boxed{\text{DATA/ANALYSIS}}$ Metronome will beat once a second, and our group will observe the distance traveled from the start and record this.

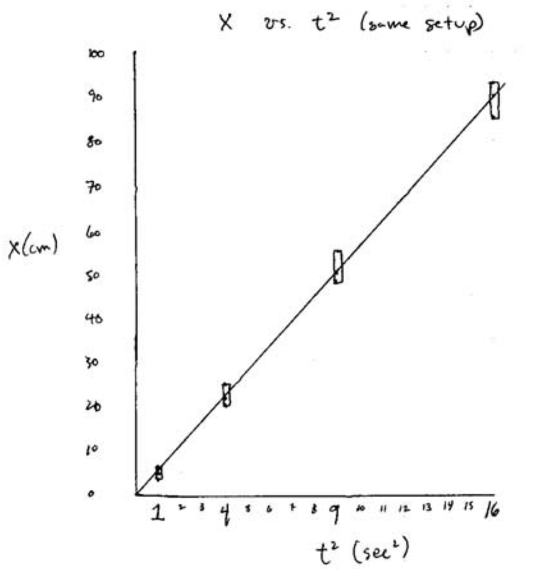
	time (sec)	0	1	2	3	4
Trial 1	x (cm)	10	15	32	60	100
	Δx	0	5	~~85~~ 22	50	90
Trial 2	x	10	16	35	65	103
	Δx	0	6	25	~~45~~ 55	93
Trial 3	x	10	14	30	58	95
	Δx	0	4	20	48	85

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

$= \cancel{60}$ 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,

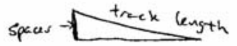
$$x = m t^2 \quad \text{where } m = 5.7 \text{ cm/s}^2$$

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.

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



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

calculated

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

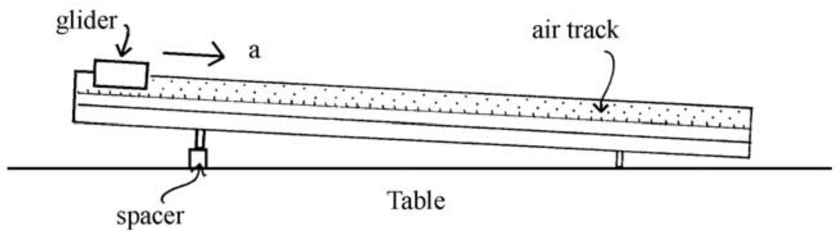
Very close! (~ 5% error)

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.

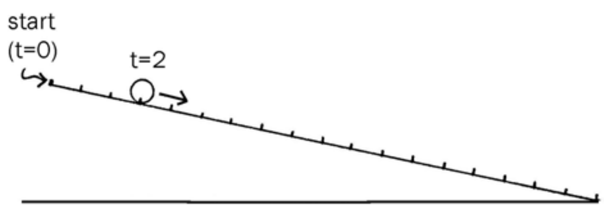


- Let x be the distance traveled in a certain time t. Graph the data x vs. t. Is x a linear function of t?
- Graph the data x vs. t^2 (this is accomplished by squaring all the time values, and plotting the according distances). Is x a quadratic function of t? Include (x,t)=(0,0) on each graph.
- Use 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?

Problems

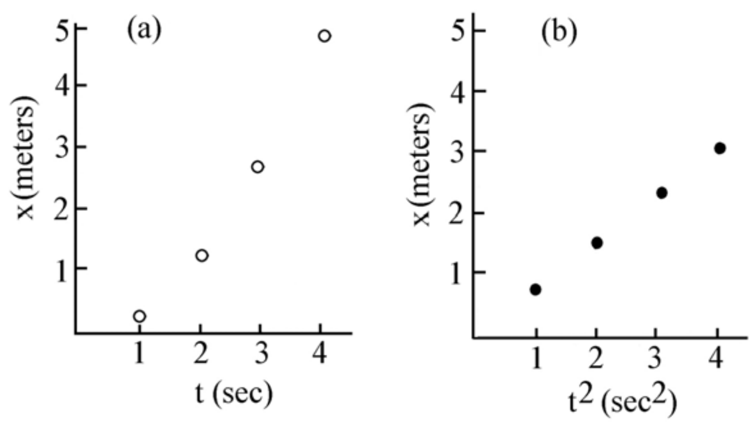
2.1.1. A ball accelerates from rest down an inclined plane. Its position after 2 seconds is marked on the drawing.

a. Mark the positions of the ball after a total time of 3 and 4 seconds has elapsed since it was at rest.
b. Where was the ball after one second from start?
c. If the velocity of the ball was 5 m/s after 2 seconds, what is its velocity after 3 seconds?



2.1.2. You drop stones down vertical mine shafts. For mine shaft A you hear the stone hit the bottom after 3 beats of your pulse. For mine shaft B you hear the stone hit after 5 beats of your pulse. How many times deeper is B than A?

2.1.3. Find the acceleration for both sets of data plotted below.



2.1.4. You are given an inclined plane, which makes a fixed angle θ with the horizontal. This angle is unknown to you. The length of the inclined plane is 2 m. In your first experiment, you release an object from rest at the top of the inclined plane and it takes 1 sec to reach the bottom of the plane. In the second experiment, you give the same object a slight push while letting it go at the top of the inclined plane. This time the object takes 0.5 sec to reach the bottom. What is the initial speed of the object in your second experiment?

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:

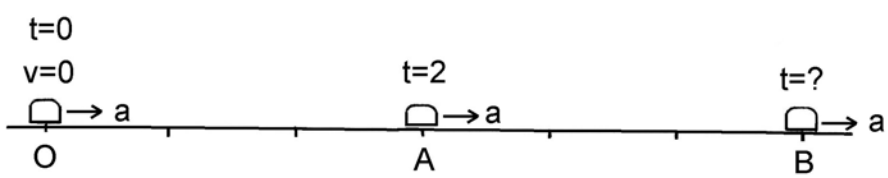
- Determine how long it takes to go a distance d (about 0.75 meter).
- Determine how long it takes to go 2d.
- Did it take twice as long? How is t related to x?

Problems

2.2.1. For accelerated motion if the initial velocity is $v_0 = 0$, then $x(t) = \frac{1}{2}at^2$. Invert this equation to write t as a function of x, i.e., t(x).

2.2.2. For accelerated motion if the initial velocity is $v_0 \neq 0$, then $x(t) = v_0 t + \frac{1}{2}at^2$. Invert this equation to write t as a function of x, i.e., t(x).

2.2.3. An object starts at O from rest at t=0 with a constant acceleration a. At t=2, its position is at A. If it continues with the same constant acceleration to position B, what time does it reach B?



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.

Problems

2.3.1. Starting from rest, how long does it take a massive object (ignore air resistance) to fall to the ground

a. from your eye level, while standing.
b. from the top of a typical tree.
c. from the top of a 10 story building.

2.3.2. You throw a ball straight up besides a building with an initial speed of v. The ball rises to a highest point at half the building's height. You now wish to throw the ball so that it just rises to the top of the building. What should be the initial speed of the ball in the second case?

2.3.3. A ball is shot vertically upward from the surface of a planet in a distant solar system. The acceleration due to gravity on this planet is not known, but can be figured out from the observation that the ball reaches a maximum height of 25 m and remains in the ‘air’ (up and down) for 5 seconds.

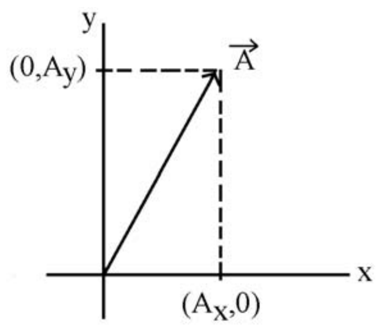
a. What is the magnitude of the acceleration due to gravity on this planet?
b. What is the magnitude of the initial velocity of the ball?

2.3.4. A ball falls from rest from the top of a building and passes a window 1.5 meters high in 0.1 second. How far above the top of the window did the ball start to fall?

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.



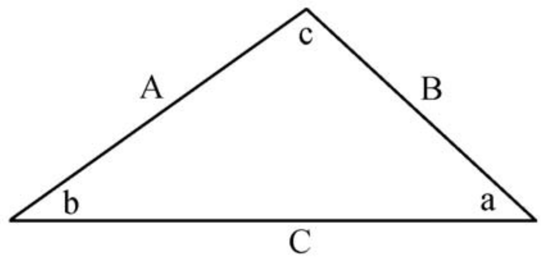
- Find the coordinates of the head of the vector. What are the x and y components of the vector, A_x and A_y?
- Measure the length and the angle, from the x-axis, of the vector. Calculate the components using trigonometry and compare to those measured above.
- Draw a second vector $\vec{B}$, different 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 $\vec{E} = \vec{A} \times \vec{B}$ with the formula $E = AB\sin\theta$, and the right hand rule. The vector $\vec{E}$ is perpendicular to what plane?

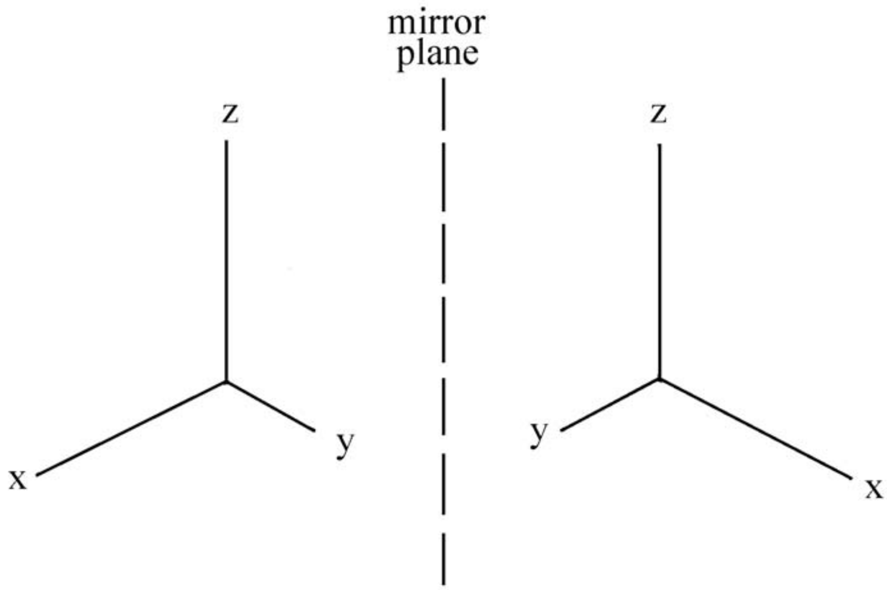
- Find $\vec{F} = \vec{B} \times \vec{A}$ and compare to $\vec{E} = \vec{A} \times \vec{B}$. Does the cross product commute?

3.5. Right and Left Hand Rules

Lab Demo

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

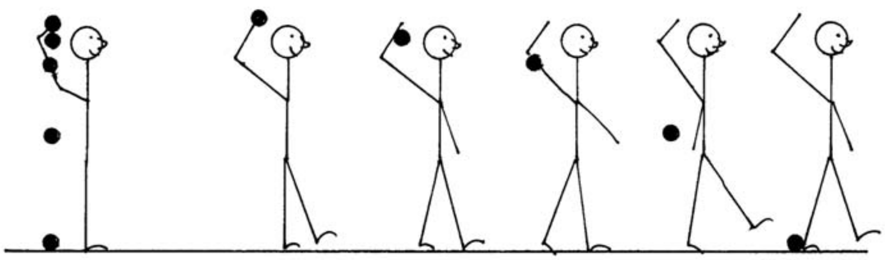
- Use the right hand and left hand rules to determine the direction of travel of the screw (or nut on the screw).
- Compare the mirror images of the screws, motions, and hands.



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

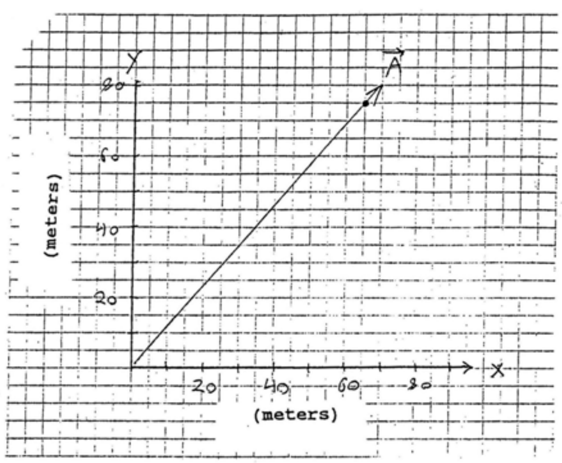
Consider a projectile motion problem provided by your instructor with an initial velocity (magnitude and direction). Write an expression for the position vector $\vec{r}(t)$. (This is the Equation of Motion.) Let the acceleration of gravity be $\vec{g} = 9.8\text{m}/\text{s}^2$, down. Graph $\vec{r}(t)$ 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 $\vec{r}_o(t) - r(t)$?

Problems

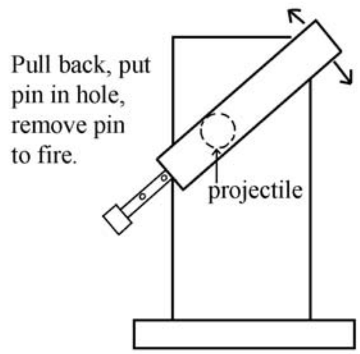
4.2.1. The vector $\vec{A}$ on the graph below is the path of a projectile launched from the origin *in the absence of gravity*. The projectile's position (65 m, 75 m) is shown at t=2.5 sec after launch.

a. On the graph plot the position of the projectile at t=2.5 sec *in the presence of gravity*, g=9.8 m/s^2, down.
b. What is the x-component of the velocity at t=2.5 sec *in the presence of gravity*?



4.3. Projectile Motion

Lab Demo



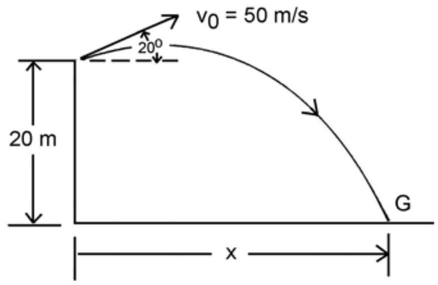
Set the projectile launcher with the barrel vertical. Shoot the projectile ball straight up and measure how high it goes. From this calculate the initial velocity, v_o. Try this for different spring compressions Δx (preferably on the "medium" setting). Plot a graph of v_o versus spring compression. How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

Problems

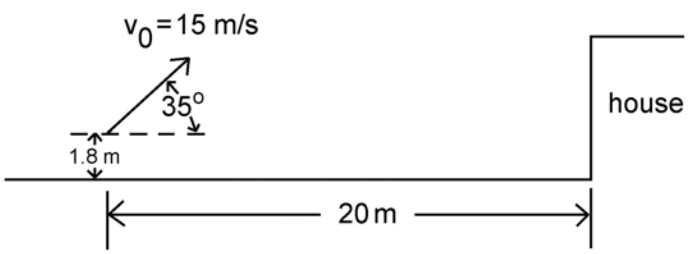
4.3.1. A projectile is fired at an angle of 20^o above the horizontal off the top of a cliff 20 m high. The magnitude of the initial velocity of the projectile is 50 m/s. The projectile reaches the ground at the point G shown in the figure.

a. What is the velocity of the projectile at the top of its trajectory?
b. What is the acceleration of the projectile at the top of its trajectory?
c. How long does the projectile remain in the air?
d. How far from the cliff does it hit the ground?
e. Find the velocity of the projectile (magnitude and direction) right before it hits the ground.



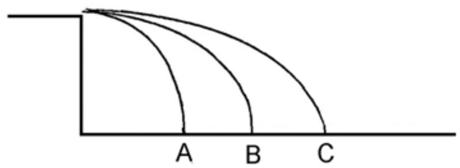
4.3.2. A boy throws an egg with a velocity of 15 m/s at an angle of 35^o from the horizontal at a house 20m away. The release point is 1.8m above the ground.

a. How long is the egg in the air?
b. How high above the ground does the egg hit the house?
c. What is the velocity of the egg when it hits the house? When it hits, is the egg going up or down?



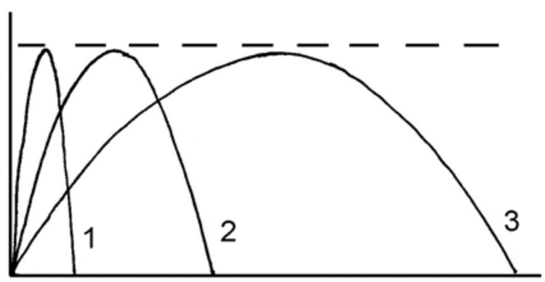
4.3.3. Drawn below are three trajectories of an object leaving a platform with a horizontal velocity.

a. Rank the trajectories in order of least to greatest time of flight (or if same, so state).
b. Rank the trajectories in order of least to greatest total velocity upon impact (or if same, so state).

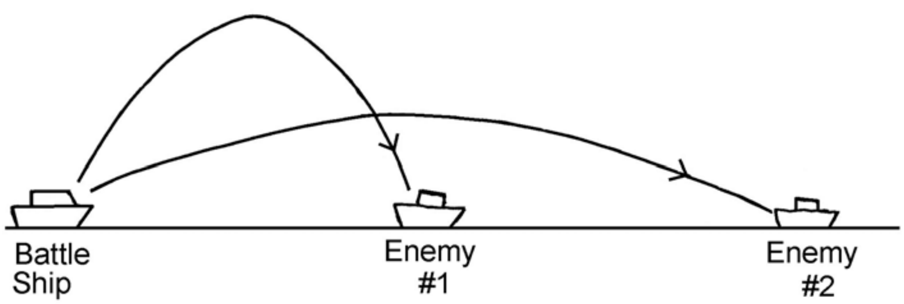


4.3.4. Drawn below are three trajectories of an object thrown from ground level.

a. Rank the trajectories in order of least to greatest time of flight (or if same, so state).
b. Rank the trajectories in order of least to greatest total velocity upon impact (or if same, so state).



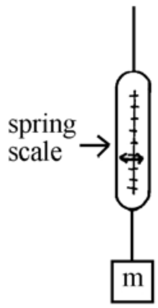
4.3.5. A battleship simultaneously fires two shells at enemy ships. If the shells follow the trajectories shown, which ship gets hits first?



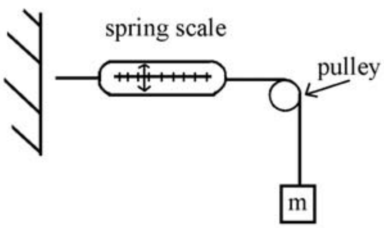
5.1. Static Forces

Lab Demo

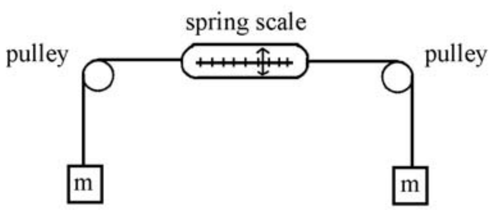
Connect a string to a spring scale and then to a mass (m=1 to 5kg, much larger than the scale), as drawn. What tension in the string is indicated by the scale?



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



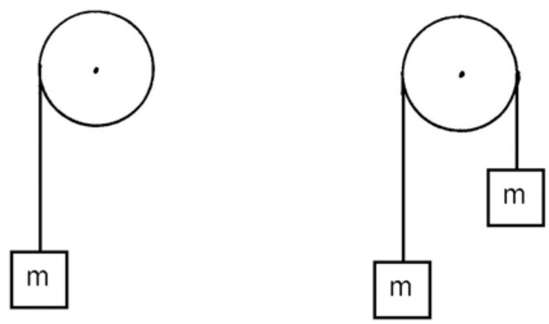
- Now take two equal masses, hang them by strings over pulleys and place the spring scale horizontally between the two, as drawn. What is the tension?



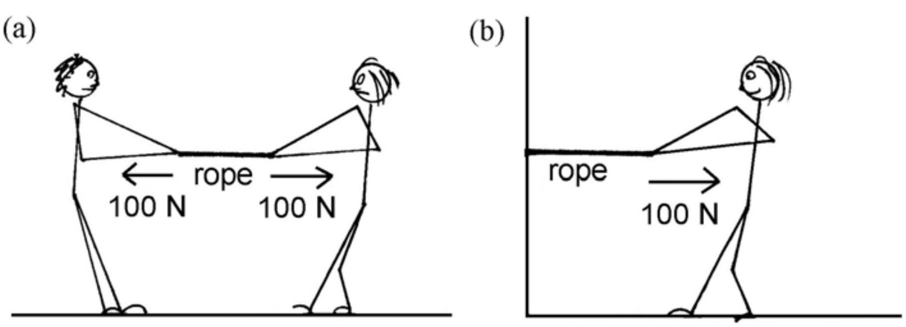
- Now put a second spring scale in the arrangement (anywhere). What do the scales read?

Problems

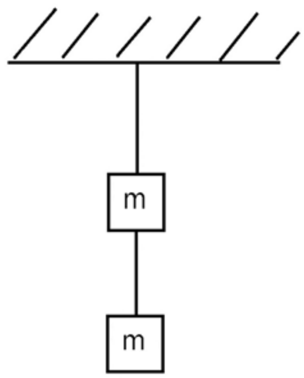
5.1.1. a. A mass m is hanging from a pulley in a locked position. Draw the direction of the tension force acting on the mass. What is the magnitude of the tension force on the mass? Next, draw the direction of the tension force acting on the pulley. What is the magnitude of the tension force on the pulley? Finally, what is the tension in the string?
b. Two equal masses m are hanging by a string over a massless, frictionless pulley as shown in the figure. Draw the direction of the tension force on each mass. What is the magnitude of this tension force? Now, draw a Free-Body-Diagram (FBD) for the pulley showing the direction of the tension force(s) acting on it.



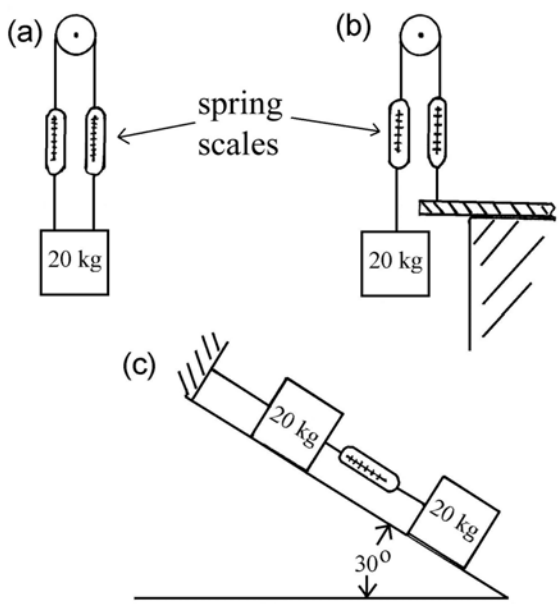
5.1.2. a. Two women have a tug-o-war and each pulls equally with a force of 100 newtons on the rope as drawn. In this stalemate, what is the tension in the rope?
b. Now one of the women ties the rope to a fixed anchor in a wall. She pulls on the rope with a force of 100 newtons; what is the tension in the rope?



5.1.3. Mass m is hanging by a massless cord from another mass m, also hanging by a massless cord, as shown in the figure. If the masses are at rest, what is the tension in each cord?



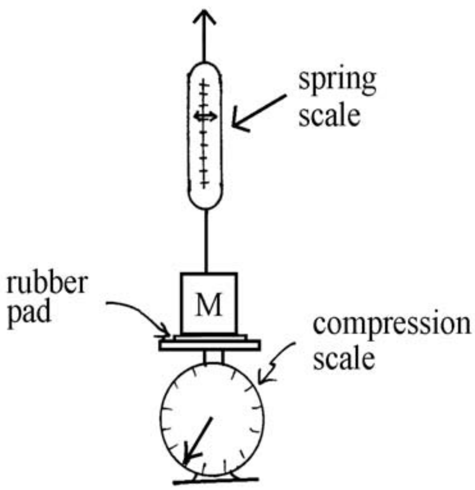
5.1.4. What will be the readings in the spring scales in newtons for the three cases shown below? The strings and scales are massless and the inclined plane is frictionless.



5.2. The Normal Force

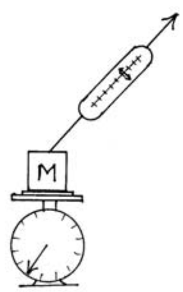
Lab Demo

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!

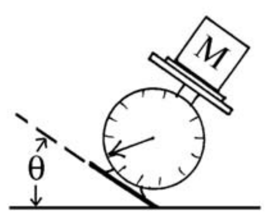


- Take a spring scale and pull vertically upward (see drawing). Record the normal force (on the compression scale) for different upward forces and make sense of the relationship between the upward pull, the reading on the compression scale and the force of gravity.

- 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.



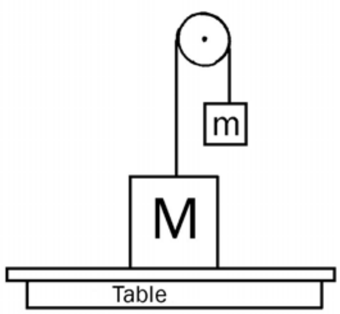
- Now tip the scale so that the platform is at an angle θ from the horizontal. The scale is still reading the normal force (normal to what?). Find the relationship between N, mg and θ.



- 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?

Problems

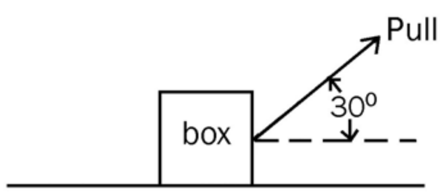
5.2.1. In the figure below, find the normal force of the table acting on the mass M=100 kg, if mass m=30 kg.



5.2.2. A person of mass 70 kg stands on a scale in an elevator. What will be the reading of the scale (in newtons) if:

a. the elevator is moving up with a constant speed of 2 m/s,
b. the elevator is moving down with a constant speed of 2 m/s,
c. the elevator is moving up with a constant acceleration of 2 m/s^2,
d. the elevator is moving down with a constant acceleration of 2 m/s^2.

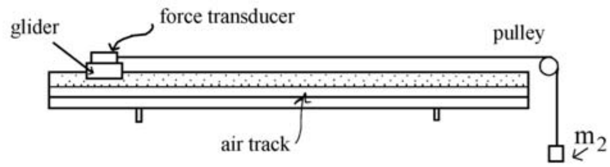
5.2.3. A person moves a box of mass 5 kg on a frictionless surface by pulling on a rope tied to the box. The rope makes an angle of 30^o to the horizontal. Find the normal force acting on the box when the applied pull on the rope is (a) 10 N, (b) 49 N, and (c) 98 N.



5.3. Two-Body Accelerated Motion

Lab Demo

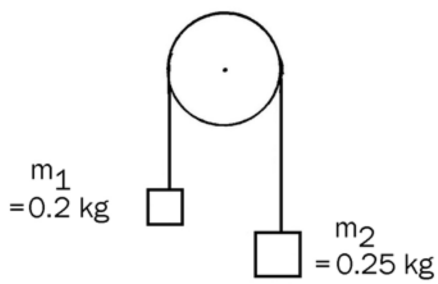
Set up and level the air track. Put a glider on it and on the glider put the force probe and some mass so that the total mass, call it m_1, is much larger than m_2. Attach a string to the transducer part of the force probe and run it over a pulley at the end of the track (and table) to another mass,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



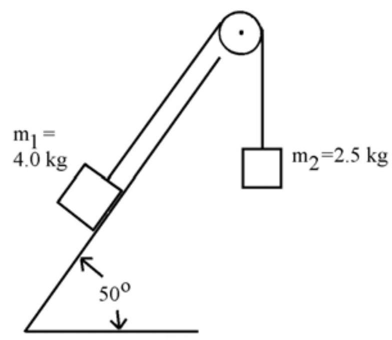
- Hold the glider stationary and measure the tension in the string. What is this due to?
- Let the glider go (with the air track operating) and measure the tension in the string during the motion. Why is it less than the tension when stationary?
- Measure the distance m_2 falls and the time to fall and 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.

Problems

5.3.1. The acceleration due to gravity g can be measured by *Atwood's machine* shown below. If the mass m_2 falls a distance of 0.9 m from rest in 1.3 sec, what is the measured value of g?



5.3.2. In the figure below m_1=4.0 kg and m_2=2.5 kg. What is the magnitude and direction of acceleration of the mass m_2? What is the tension in the string? The pulley is massless and frictionless and the ramps are frictionless.



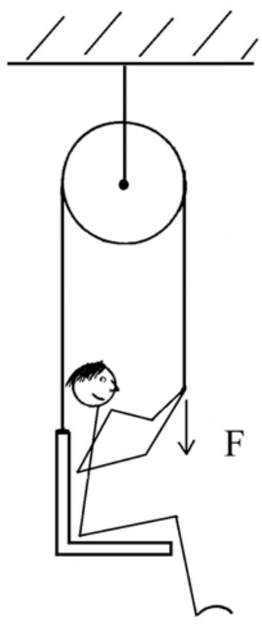
5.4. The Bosun's Chair

Lab Demo

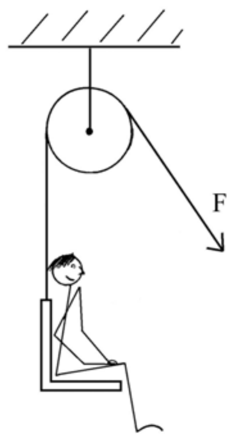
Support yourself in the Bosun's chair by holding the rope in your hand. Note the tension in the rope. Next tie off the rope to an external support or have a strong, and heavier, friend hold it. What is the tension now? Show the force diagram and explain.

Problems

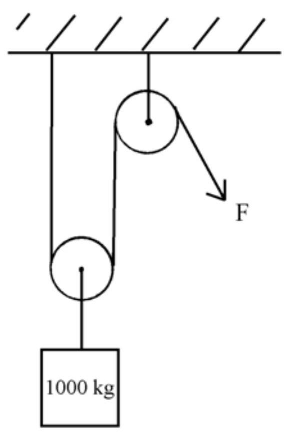
5.4.1. Consider the situation where the person sitting in the bosun's chair is applying the force on the cable. If the combined mass of the person and the chair is 100 kg, what magnitude of the applied force is necessary if the person is to rise with a (a) constant velocity of 1.5 m/s and (b) a constant acceleration of 1.5 m/s^2? In each case, what is the magnitude of the force on the ceiling from the pulley system?



5.4.2. Now, consider the situation where a friend of the person sitting in the bosun's chair is applying the force on the cable. If the combined mass of the person and the chair is 100 kg, what magnitude of the applied force is necessary if the person is to rise with a (a) constant velocity of 1.5 m/s and (b) a constant acceleration of 1.5 m/s^2? In each case, what is the magnitude of the force on the ceiling from the pulley system?



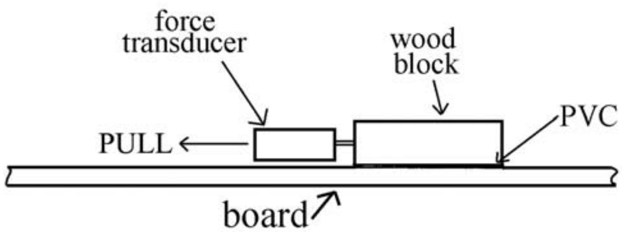
5.4.3. Consider the situation drawn below. What is the magnitude of the applied force F, if the mass of 1000 kg moves up with (a) constant velocity of 1.5 m/s and (b) a constant acceleration of 1.5 m/s^2?



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.

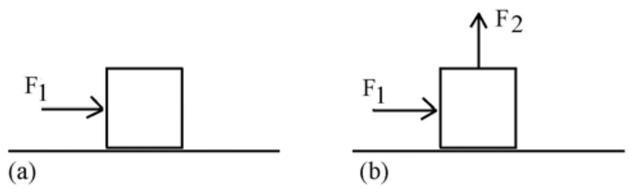


- Examine the recorded trace of the force as a function of time and make sense of it relative to the concepts of static and kinetic friction.
- Calculate the friction coefficients μ_s and μ_k.
- Redo with different mass stacked on the original mass and find how friction depends on the normal force.
-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

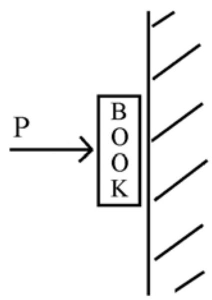
Problems

6.1.1. A box of mass 3 kg is at rest on the floor. The coefficients of static and kinetic frictions between the block and the floor are $\mu_s = 0.4$ and $\mu_k = 0.2$, respectively. A horizontal force $\vec{F}_1$ is applied to the box (see figure a).

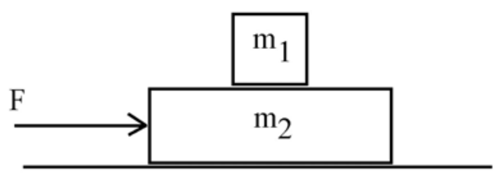
a. What minimum value of F_1 is required so that box will start moving?
b. When $\vec{F}_1$ has a magnitude of 8 N, the box does not move. What is the friction force acting on the box?
c. Instead of increasing F_1 to move the box, keep F_1=8 N fixed, but apply a *vertical* force $\vec{F}_2$ on the box (see figure b). What minimum value of F_2 is required so that box will start moving?



6.1.2. You can press a book hard against a rough wall so that the book does not slide down the wall. Suppose that the book has a mass of 0.75 kg and the coefficient of static friction between the book and the wall is 0.2. What is the minimum value of your pressing force, applied perpendicular to the surface of the book that will keep the book from sliding? (By the way, what keeps your pants up?)



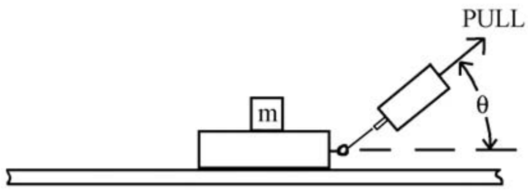
6.1.3. Mass m_1 rests on a slab of mass m_2. A force $\vec{F}$ is applied to the mass m_2 as shown in the figure. As a result, m_2 and m_1 move together (i.e., m_1 does not slide on m_2) with a certain acceleration a. The surface on which m_2 is placed and the surface between m_1 and m_2 both have friction. Draw a Free-Body-Diagram (FBD) for the masses m_1 and m_2 showing the directions of all relevant forces acting on them. If you are showing any friction force, you must mention whether this is a static friction force or a kinetic friction force. Since F does not directly touch m_1, in what manner does F cause m_1 to move? In what manner does F **not** cause m_1 to move?



6.2. Static and Kinetic Friction--Inclined Pull

Lab Demo

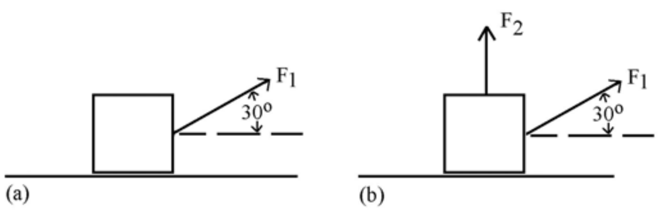
Use the same block and plane (still level) as in 6.1. Pull on the block with the force transducer at an angle θ above horizontal (say 30 or 45 or 60°). Both measure and calculate, from the μ of 6.1, the pull force where it begins to slide. Don't forget to include a force diagram.



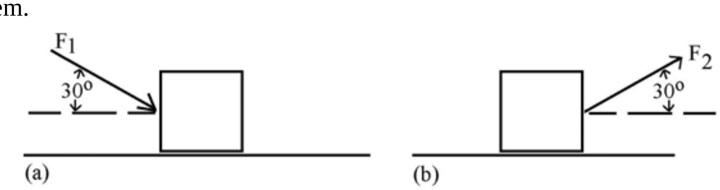
Problems

6.2.1. A box of mass 3 kg is at rest on the floor. The coefficients of static and kinetic frictions between the block and the floor are $\mu_s = 0.4$ and $\mu_k = 0.2$, respectively. A force $\vec{F}_1$ is applied to the box at a *fixed* angle of 30^o above the horizontal. (see figure a).

a. What minimum value of F_1 is required so that box will start moving?
b. When $\vec{F}_1$ has a magnitude of 8 N, the box does not move. What is the friction force acting on the box?
c. Instead of increasing F_1 to move the box, keep F_1=8 N fixed, but apply a *vertical* force $\vec{F}_2$ on the box (see figure b). What minimum value of F_2 is required so that box will start moving?



6.2.2. You want to move a big box of mass 100 kg along a floor. The coefficient of static friction between the box and the floor is $\mu_s = 0.3$. In case (a) you push the box with a force $\vec{F}_1$ at an angle of 30^o as shown in figure (a). In case (b) you pull the box with a force $\vec{F}_2$ at an angle of 30^o as shown in figure (b). Compute both the minimum F_1 and F_2 necessary to move the box and compare them.

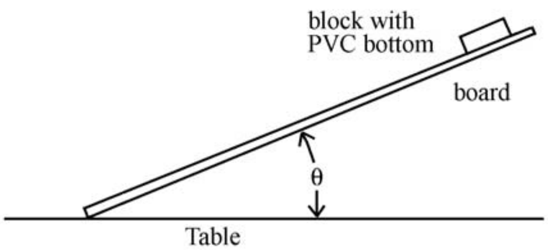


6.3. Angle of Slip

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.

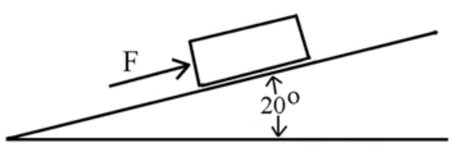
- Measure the angle when the mass begins to slip and from this calculate μ_s. Compare to 6.1.
- Do this with more mass stacked on the block. Does the mass matter?
- What is the frictional force when the angle is less than the maximum value and the block is not moving?



Problems

6.3.1. A sled of mass m=8 kg rests on a plane inclined at 20^o to the horizontal (see figure). Between the sled and the plane, the coefficient of static friction is 0.50 and the coefficient of kinetic friction is 0.25. The sled is initially at rest but a force $\vec{F}$ can be applied to the sled parallel to the plane to make it move up the plane. The magnitude of $\vec{F}$ can be varied.

a. Find the magnitude and direction of the frictional force acting on the sled before any force $\vec{F}$ is applied to the sled. i.e., when F=0.
b. What is the minimum magnitude of $\vec{F}$ needed that will start the sled moving up the plane?
c. Find the magnitude of the frictional force acting on the sled when F=127 N.

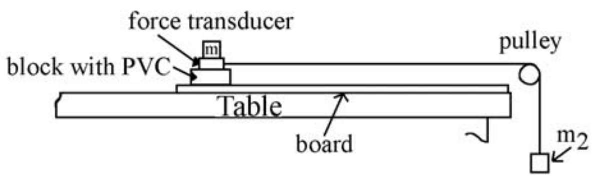


6.3.2. A skier of unknown mass moves down a ski slope of 20^o with a constant velocity. What is the coefficient of kinetic friction μ_k between the skier and slope?

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.

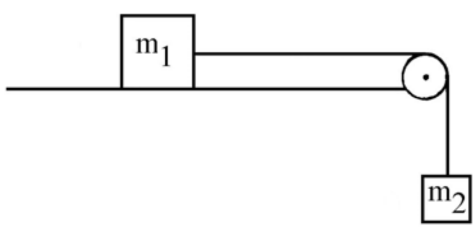


- Hold m_1 stationary and measure the tension in the string. What is the tension due to?
- Let the mass go. Measure the tension while in motion and compare to the static tension.
- Measure the distance m_2 falls and the time to fall and hence its acceleration.
- Calculate the tension and acceleration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

Problems

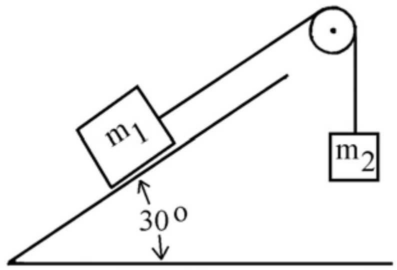
6.4.1. In the figure below m_1=20.0 kg and m_2 can be varied. The coefficient of static friction μ_s between m_1 and the surface is 0.3 and the coefficient of kinetic friction μ_k is 0.15.

a. Both m_1 and m_2 are at rest initially. Mass of m_2 is now increased slowly. What is the acceleration of the system when m_2=4 kg?
b. What is the acceleration of the system when m_2=10 kg?



6.4.2. In the figure below m_1=20.0 kg and m_2 can be varied. The coefficient of static friction μ_s between m_1 and the ramp is 0.3 and the coefficient of kinetic friction μ_k is 0.15.

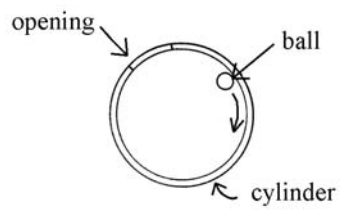
a. What is the *minimum* value of m_2 such that the whole system is at rest?
b. What is the *maximum* value of m_2 such that the whole system is at rest?
c. What is the acceleration of the system when m_2=15 kg?



6.5. Circular Motion

Lab Demo

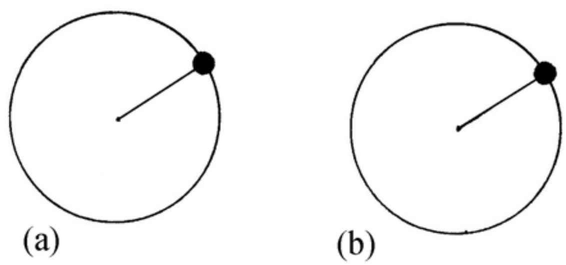
Put the small ball inside the metal cylinder on the table. Give the ball a push tangentially along the inner surface of the cylinder. The ball travels in circular motion. What force must exist for this circular motion? What is the agent causing the centripetal force? What happens when the ball comes 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.



Problems

6.5.1. A tennis ball attached to a string is being swung with a constant speed in circle in a clockwise direction.

a. Draw the direction of the velocity of the ball and the net force acting on the ball on figure (a).
b. If the string breaks at this instant, draw how the ball will fly off on figure (b).



6.5.2. A 1200 kg car moving at 60 mph goes over a rounded hilltop of radius 10 m. What is the normal force acting on the car when it is at the top of the hill? At what minimum speed (in miles per hour) will the normal force on the car be zero? What will this feel like in the car?

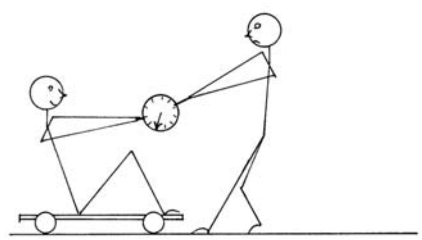
6.5.3. A 1200 kg car moving at 60 mph goes over the rounded bottom of a valley of radius 10 m. What is the normal force acting on the car when it is at the bottom of the valley? Can the normal force be made zero in this case by changing the speed of the car?

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.

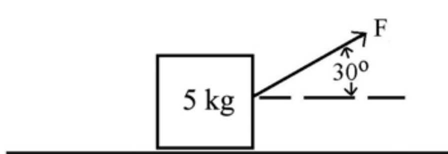
- Calculate the work done by the puller and the kinetic energy of the person/cart system and thereby test the work-energy theorem. Yes, there is considerable experimental error, but you can still test the work-energy theorem within the uncertainty of the measurement (approximately how much energy would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



Problems

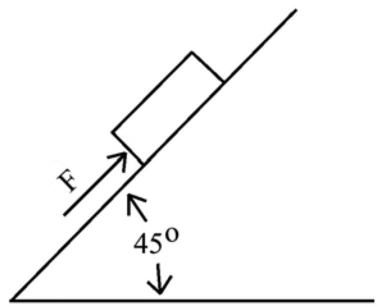
7.1.1. A person moves a box of mass 5 kg on a frictionless surface by pulling on a rope tied to the box. The magnitude of the applied force is 4 N. The rope makes an angle of 30^{o} to the horizontal.

a. If the box moves 2.5 m, find the work done by (i) the applied force, (ii) the normal force, and (iii) the gravitational force.
b. What is the *total* work done on the box?
c. If the box has started from rest, what is its speed after it has moved 2.5 m?

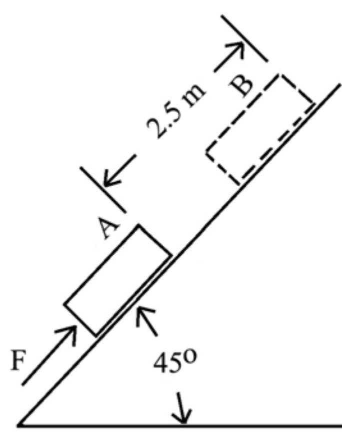


7.1.2. A person moves a box of mass 5 kg up a frictionless 45^o ramp, by applying a force to the box parallel to the ramp. The magnitude of the applied force is 40 N.

a. If the box moves 2.5 m, find the work done by (i) the applied force, (ii) the normal force, and (iii) the gravitational force.
b. What is the *total* work done on the box?
c. If the box has started from rest, what is its speed after it has moved 2.5 m?



7.1.3. A person moves a box of mass 5 kg up a frictionless 45^o ramp, by applying a force to the box parallel to the ramp. During the course of motion, the box moves a distance of 2.5 m from A to B (see figure) with a constant velocity of 1.2 m/s. While the box moves from A to B, find the work done by (i) the applied force, (ii) the normal force, and (iii) the gravitational force.
(b) What is the *total* work done on the box as it moves from A to B? How is that consistent with the fact that it has moved with a constant velocity of 1.2 m/s from A to B?

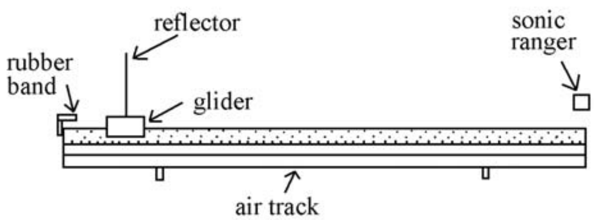


7.2. Spring Potential to Kinetic Energy

Lab Demo

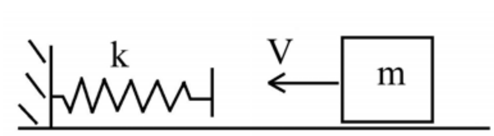
Set up the air track level. Adjust the glider to have a mass in the range 0.1 to 0.3kg. Stretch a rubber band across the bumper at the end of the track.

- 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.

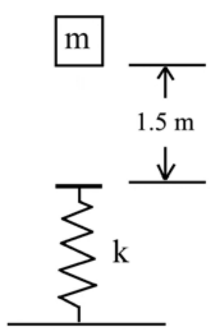


Problems

7.2.1. A mass m=0.5 kg has been moving with a constant velocity of 0.8 m/s along a horizontal, frictionless surface before it hits a horizontal spring of spring constant k=500 N/m and compresses it. What is the maximum compression of the spring?



7.2.2. A mass m=0.5 kg is dropped from a height of 1.5 m above the end of an uncompressed vertical spring of spring constant k=500 N/m. What is the maximum compression of the spring?

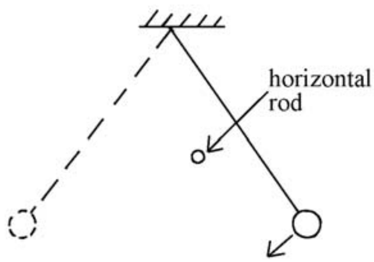


8.1. Path Independence

Lab Demo

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

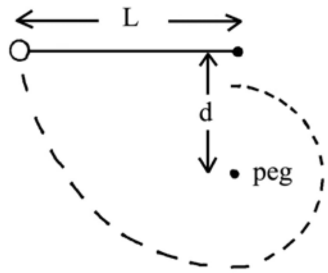
- Pull the pendulum to the side, with the string taut, and measure the mass's height above the table. Let the mass go and measure how high it gets when it comes to a momentary stop at the other side of its swing. Compare heights.
- Repeat but place a fixed, horizontal rod in the path of the string as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



Problems

8.1.1. A ball is attached to a horizontal cord of length L whose other end is fixed. A peg is located at a distance d directly below the fixed end of the cord. The ball is released from rest when the string is horizontal.

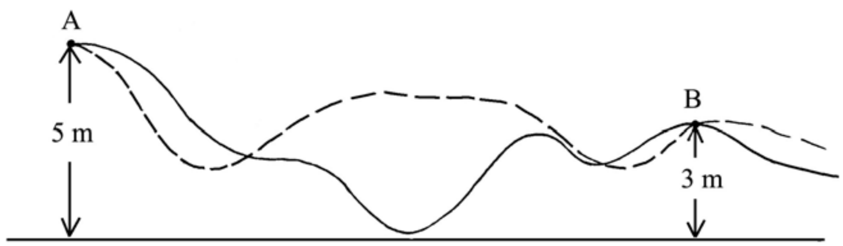
a. If d=0.75L, find the speed of the ball when it reaches the top of the circular path about the peg.
b. Will the ball be able to make a complete circle about the peg if d=0.5L? What is the minimum distance d such that the ball will be able to make a complete circle about the peg after the string catches on the peg?



8.1.2. a. A ball is thrown *down* vertically with an initial speed v_0 from a height h. What is its speed right before it hits the ground?
b. If, instead, the ball is thrown vertically *upward* with the same initial speed v_0 from the same height h, what will be its speed right before it hits the ground?

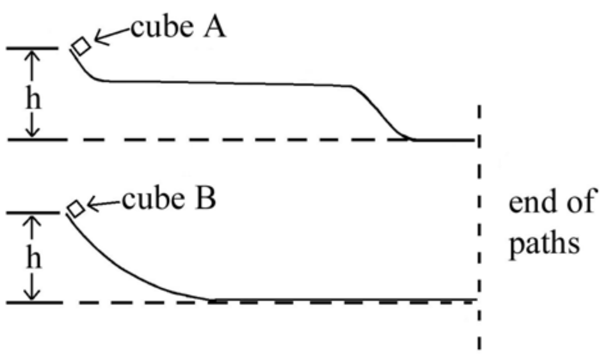
8.1.3. Two blocks each with a mass of 0.2 kg start from rest at the point A at a height of 5.0 m above a horizontal surface (see figure). They both reach the point B at a height of 3.0m but they take two different paths drawn as a solid line for block-1 and a dashed line for block-2. Neglect friction.

a. Find the speeds of the two blocks at point B.
b. What is the work done by the gravitational force for each block as they move from A to B?



8.1.4. Two identical ice cubes slide frictionlessly along the two paths shown below. Each cube starts initially with zero speed at a height h above the end of the path.

a. Which ice cube A or B, has a greater speed at the end of the path? If the speed is the same, so state.
b. Which ice cube A or B, gets to the end first? If the time is the same, so state.

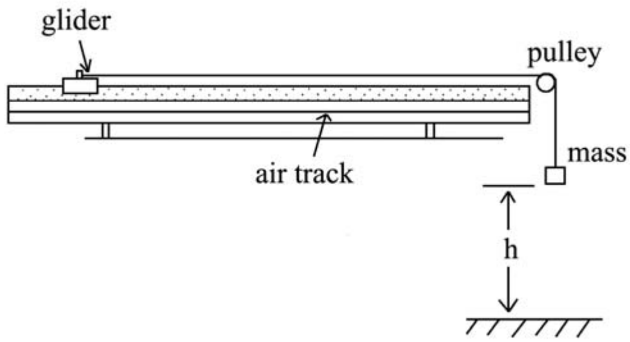


8.2. Gravitational Potential to Kinetic Energy

Lab Demo

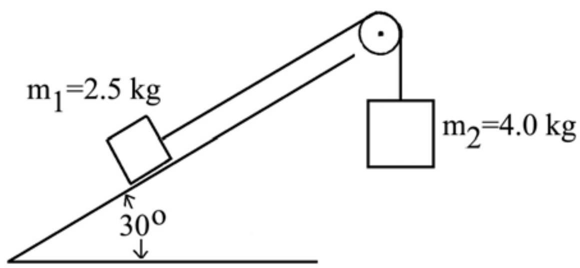
Adjust the air track so it is horizontal and put a glider on it. Attach a string to the glider, run this over a smart pulley and then attach a mass to the other end of the string (see drawing). Masses on the order of 0.1 to 0.3 kg will work well.

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



Problem:

8.2.1. In the figure below m_1=2.5 kg and m_2=4.0 kg. What is the speed of m_1 after it falls a distance of 0.7 m from rest? The pulley is massless and frictionless and the ramp is frictionless.



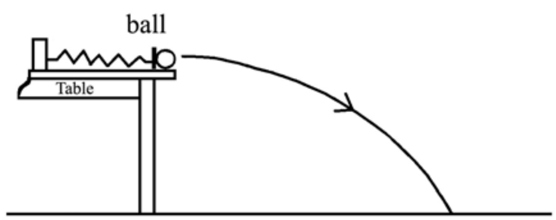
8.3. Spring, Gravitational and Kinetic Energies

Lab Demo

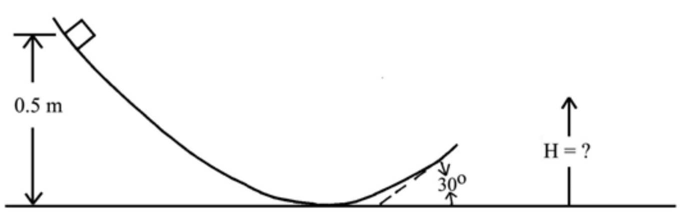
- Return to the projectile launcher of 4.3. Once again shoot it vertically and determine the maximum height of the projectile as a function of the compression. (Make sure you get the zero of compression correct.) Plot h(max) vs. Δx. Are they linearly related? Is there a better way to plot this? What 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.

Problems

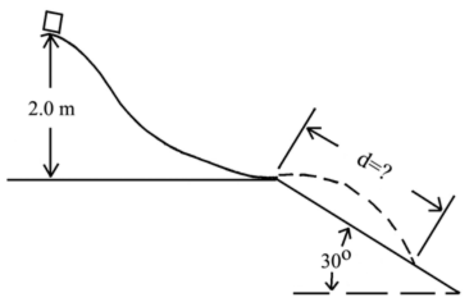
8.3.1. Consider a projectile launcher placed horizontally on the edge of a frictionless table. When the spring is compressed by 1.2 cm, the ball lands on the floor at a distance of 1.9 m from the edge of the table. What should be the compression of the spring so that the ball lands on the floor at a distance of 2.3 m from the edge of the table?



8.3.2. A block starts from rest at a height of 0.5 m (see figure) and slides down a frictionless metal slide. As it leaves the slide, its velocity makes an angle of 30^o with the horizontal. What is the maximum height H reached by the block after it leaves the slide? If it left the slide at 90^o, i.e., vertically, what would the maximum H be?



8.3.3. A block starts from rest at a height of 2 m above the lower end of a frictionless ramp and slides down. The block takes off at the horizontal edge of the ramp (see figure). Determine the distance d shown in the figure where it lands.

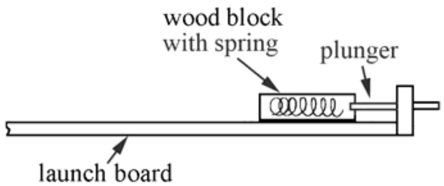


8.4. Dissipation of Mechanical Energy by Friction

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.



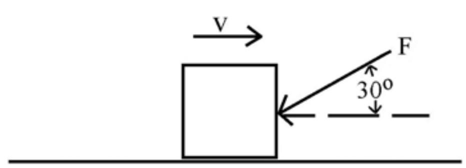
- Vary x and check the functionality, i.e., plot d as a function of x and find a way to make these graphs linear (as an example, recall that for accelerated motion a graph of x vs. t^2 is linear.)

Problems

8.4.1. At an accident scene on a level road, police investigators measured a car's skid mark to be 90 m long. The investigators want to figure out the speed of the car right before the driver slammed on and locked the brakes. They know that the coefficient of kinetic friction between the car’s tires and the road is $\mu_k = 0.40$. What was the speed of the car right before the driver slammed on and locked the brakes?

8.4.2. To slow down a moving wood crate of mass 14 kg a person applies a constant force on the crate of magnitude 40 N at 30^o to the horizontal (see figure). During the time the force is applied, the crate moves 0.50 m across a concrete floor and its speed decreases from 2.00 m/s to 0.20 m/s.

a. Compute the work done by the applied force.
b. Compute the change of kinetic energy of the crate during the time that the force is applied.
c. Find the work done by friction between the crate and the floor.
d. Find the coefficient of kinetic friction between the crate and the floor.



8.5. More Distribution of Energy

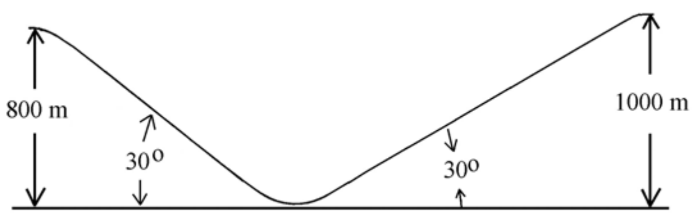
Lab Demo

Repeat 8.4 but with the plane inclined at about 20°. Shoot the mass up the plane.

Problems

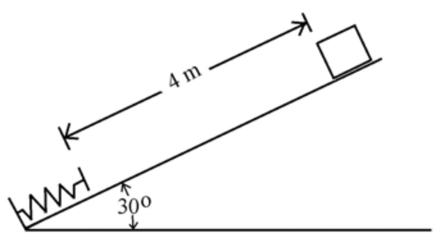
8.5.1. Two snowy peaks are of height 1000 m and 800 m above the valley between them. A ski run extends down from the top of the higher peak and back up to the top of the lower one (see figure). The slope of the peaks is 30^o.

a. A skier starts from rest on the higher peak. At what speed will she arrive at the top of the lower peak if she just coasts without using any poles. Ignore friction.
b. What will be her speed at the top of the lower peak in a similar situation if the coefficient of kinetic friction is $\mu_k = 0.05$?



8.5.2. A 2 kg block is released from rest at a distance of 4 m from a massless spring with a force constant 100 N/m that is fixed along an inclined plane of slope 30^o (see figure).

a. Find the maximum compression of the spring after the block hits it, neglecting friction.
b. Next, consider the inclined plane to be rough with a coefficient of kinetic friction $\mu_k = 0.2$. Find the maximum compression of the spring now.
c. The compressed spring rebounds and pushes the mass back, up the plane. If the inclined plane has friction, the mass will not go all the way back to its original starting position. For $\mu_k = 0.2$, find the distance the block travels back up the inclined plane after leaving the spring.



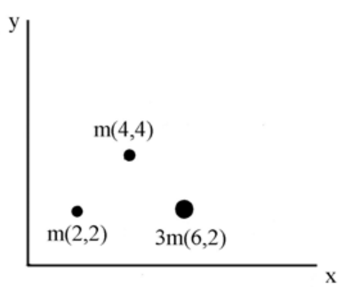
9.1. Center of Mass

Lab Demo

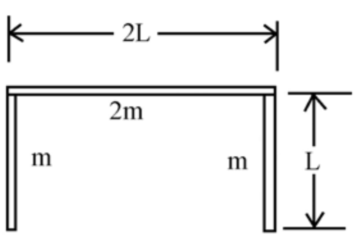
Calculate the position of the center of mass for the geometrical objects given. Try both the standard method (i.e. break up a complex geometry into a sum of simpler geometries) and the method of negative mass (ask your instructor!). Determine the center of mass experimentally (how?) and compare. Do not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

Problem

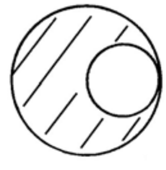
9.1.1. Find the center of mass of the three masses below.



9.1.2. Find the center of mass of *the system* of three uniform rods shown in the figure.



9.1.3. Drawn is a uniform *sphere* of radius R with a hollow section of radius R/2 cut of it just inside the outer edge. The geometric center of the big sphere is at the origin, that of the hollow one is on the x-axis. Find the center of mass of this object.

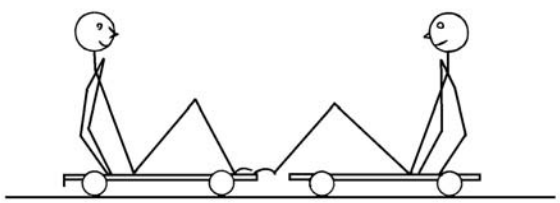


9.2. Center of Mass and Internal Forces

Lab Demo

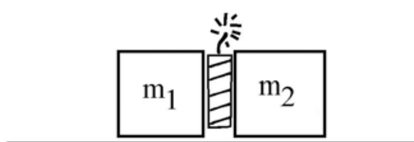
Have two people sit on two roller carts facing each other. Set up sonic rangers behind them to measure their velocities. Measure the mass of each person plus cart. Have one or both people (does it matter?) push away from the other. Measure and calculate their velocities immediately after the push.

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



Problems

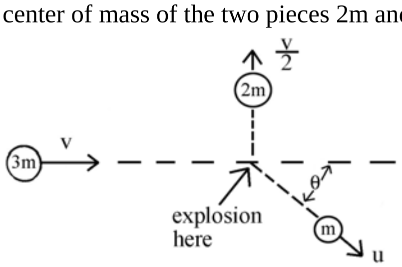
9.2.1. Two masses m_1=0.5 kg and m_2=0.2 kg, are at rest next to each other on a level air-track. One can insert a small firecracker of negligible mass in between m_1 and m_2. Right after the firecracker explodes the two masses move away from each other with speeds v_1 and v_2, respectively. If v_1=3.0 m/s, what is v_2?



9.2.2. A 55 kg woman and a 90 kg man stand 12 m apart on skateboards, holding on to the two opposite ends of a rope. The man pulls on the rope, so that the woman moves 3 m, relative to the floor, in his direction. How far from the woman is he now?

9.2.3. An object of mass 3m is moving in the direction of the positive x-axis with a speed v when, owing to an internal explosion, it breaks into two parts of mass m and 2m. The mass 2m moves away from the point of explosion with a speed of v/2 in the direction of the positive y-axis. The other mass m moves away with a speed u at an angle θ as shown in the drawing.

a. Find the angle θ.
b. Find the speed u of the mass m in terms of the original speed v of mass 3m.
c. Find the speed of the center of mass of the two pieces 2m and m after the explosion.

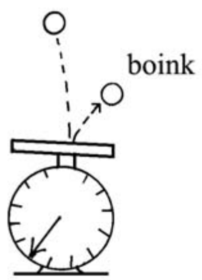


10.1. Momentum Change and Impulse

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.

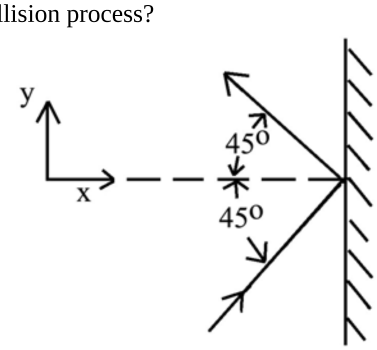
- Which ball yields the greatest impact? Which ball was the greatest change in momentum?



Problems

10.1.1. A superball of mass 0.05 kg dropped onto the floor from a height of 1 m bounces back to a height of 0.7 m. What is the change of momentum of the ball in the collision process? If the ball is in contact with the floor for 10 ms, what is the magnitude of the average force that acts on the ball during the collision process? What is the ball's average acceleration during the collision process? Compare this average acceleration with the acceleration due to gravity, g.

10.1.2. A superball of mass 0.05 kg and speed 30 m/s, strikes one of the walls of the studio at a 45^o angle and rebounds at 45^o angle as well with the same speed. What is the change of momentum Δp_x and Δp_y (see drawing) of the ball in the collision process? If the ball is in contact with the wall for 10 ms, what is the magnitude and direction of the average force that acts on the ball during the collision process?



10.1.3. On a gusty day air moving at a speed of 60 mph, strikes head-on the face of Nichols hall and comes to rest. The face of this building is 50 m wide and 65 m tall. If air's density is 1.3 kg/m^3, find the average force of the wind on Nichols hall.

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.

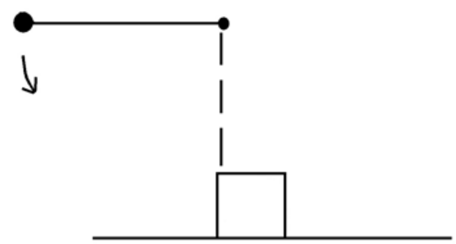
Problems

10.2.1. Consider elastic collisions between two masses m_1 and m_2 on an airtrack m_1 is initially at rest and m_2 is initially moving towards m_1 with a speed of 2 m/s. In each of the following cases, find the velocities (magnitude and direction) of the two masses right after the collision process:

a. m_1=m_2=0.5 kg,
b. m_1=0.5 kg, m_2=0.2 kg,
c. m_1=0.2 kg, m_2=0.5 kg.
d. In (a), (b), and (c) what is the relative velocity between the two masses after the collision?

10.2.2. A plastic ball is fastened to a cord that is 85.0 cm long and fixed at the far end. The mass of the ball is 0.4 kg. The ball is released when the cord is horizontal (see adjacent figure). At the bottom of its path, the ball strikes a block initially at rest on a rough surface ($\mu_k = 0.15$). The mass of the block is 1.5 kg. Assume that the collision is perfectly elastic.

a. What are the speeds of the block and the ball *right after* the ball hits the block?
b. How far does the block move before coming to rest?
c. What is the *maximum* angle that the ball makes with the vertical after it bounces back?



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

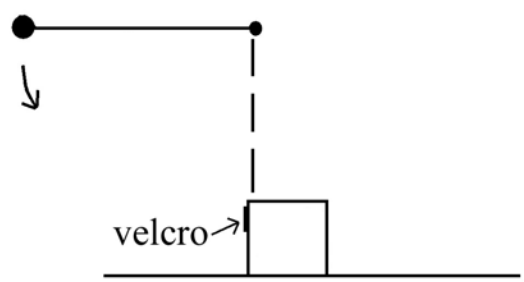
For each collision measure the final velocities, calculate them, compare theory and experiment.

Problems

10.3.1. A 1000 kg Geo Prizm collides into the rear end of a 2200 kg Ford Taurus stopped at a red light. The bumpers lock, the brakes are locked and the two cars skid directly forward 2.8 m before stopping. The police officer, knowing that the coefficient of kinetic friction between the tires and the road is 0.40 (and having studied physics in college), calculates the speed of the Prizm at impact. What was that speed?

10.3.2. A plastic ball is fastened to a cord that is 85.0 cm long and fixed at the far end. There is a bit of *velcro* attached to the plastic ball. The mass of the ball plus the velcro is 0.4 kg. The ball is released when the cord is horizontal (see figure). At the bottom of its path, the ball strikes a block initially at rest on a rough surface ($\mu_k = 0.15$). There is a bit of Velcro attached to the block as well so that when the ball hits the block they stick together. *The string breaks and the block and the ball move together on the rough surface*. The mass of the block plus velcro is 1.5 kg.

a. What is the speed of the block and the ball *right after* the ball hits the block and they stick together?
b. How far do the block and the ball move together before coming to rest?



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.

Problem

10.4.1. A 40 mile/hour freight train hits a dog standing on the tracks. The dog flies straight ahead and lands between the rails. Assume the collision is elastic.

a. Immediately after the collision what, to a good approximation, is the speed of the train
b. Immediately after the collision what, to a good approximation, is the speed of the dog? PS: The dog lived.

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.

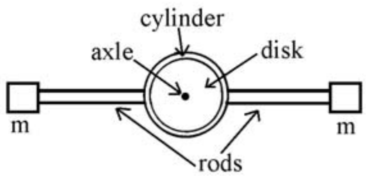
- Pull the end ball to the side and release it. What is the result of the ensuing collision? Explain using the physics of collisions (1D, elastic, same mass).
- Pull two balls on an end to the side together and release them. What happens and why?
- Pull to the side three balls, four balls. What happens,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

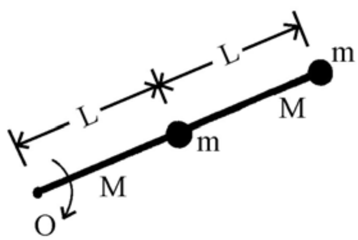


Problems

11.1.1. A turntable of radius 18 cm is rotating about an axis through its center of mass. Find the rotational inertia about this axis for a penny of mass 5 grams placed at a distance of 10 cm from the center of the turntable. You can treat the penny as a point mass.

11.1.2. Calculate the rotational inertia of a meter stick (of mass m and length L=1m) about an axis passing through one endpoint of the stick and perpendicular to the stick, given that $I=mL^2/12$ is the value relative to an axis through the center of the mass and perpendicular to the stick. Assume the width of the meter stick is << 1 m.

11.1.3. Find the rotational inertia of the combination of two particles and two sticks shown below. The particles have mass m=0.1 kg, and the sticks have mass M=0.2 kg. The length of each stick is L=0.5 m. The rotation axis passes through one endpoint of the combination denoted as O.

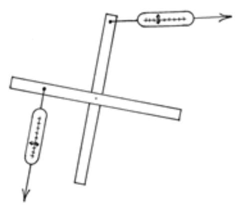


11.1.4. You are given a disk and hoop of equal mass and radius. Which one do you expect to have a larger rotational inertia about an axis passing through the center and perpendicular to the plane of the disk or hoop? Why? How does the rotational inertia of a sphere with the same mass and radius compare?

11.2. Torque

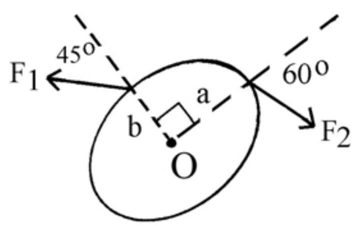
Lab Demo

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.

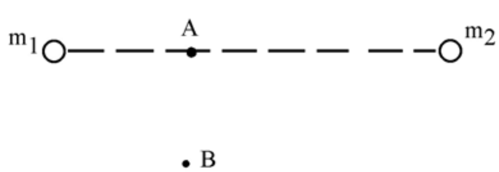


Problems

11.2.1. An object is pivoted at a point O and is acted upon by two forces $F_1=F_2=10N$ as shown. Find the net torque about O on this object when a=1.2m and b=0.8m.



11.2.2. Two particles of masses m_1 and m_2 exert equal and opposite forces, $\vec{F}_{12} = -\vec{F}_{21}$, on each other along the line joining the particles. Find the torque due to these two forces about the point A and the point B.

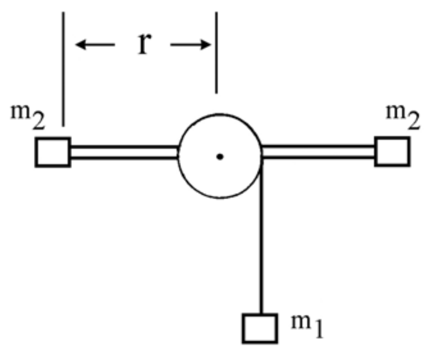


11.3. Acceleration in a Translation/Rotation System

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.

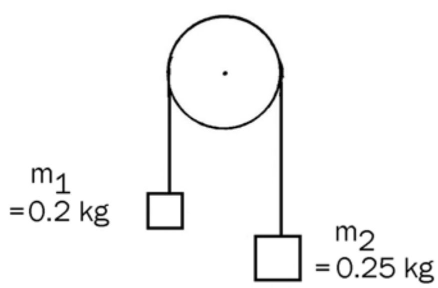
Problems

11.3.1. An object of mass m is tied to a light string wound around a wheel that has a rotational inertia I about its center of mass and radius R. The wheel bearing is frictionless and the string does not slip on the rim. When the mass is let fall from rest, the tension in the string is T, the acceleration of the mass is a, and the angular acceleration of the wheel (which rotates about its center of mass) is α.

a. Draw a free body diagram for the falling mass m and use Newton's 2nd law to write an equation connecting its acceleration a, tension T in the string, and other relevant variables.
b. Draw a diagram for the wheel showing the relevant forces acting on it and use Newton's 2nd law in angular form to write an expression connecting the angular acceleration α of the wheel, tension T, and other relevant variables.
c. Write an expression that relates the acceleration a for the falling mass and the angular acceleration α of the wheel when the string does not slip. This is the constraint that connects the translational and rotational motions.
d. For I=0.400 $\text{kg}\cdot\text{m}^2$, m=500 g, and R=33.0 cm calculate the tension in the string T and the acceleration a of the falling mass using the equations developed in parts (a) through (c).

11.3.2. Revisit the Atwood's machine considered before (5.3.1). However, unlike before, now the pulley has mass. Here, m_1=0.2 kg, m_2=0.25 kg and the pulley has a radius R=0.05 m and rotational inertia $I = 2.5\times10^{-4}\,\text{kg m}^2$.

a. Find the acceleration of the falling mass m_2 if the cord does not slip on the pulley.
b. Find the tensions in each string.

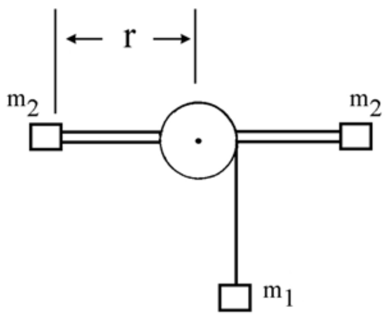


11.4. Energy Conservation in a Translation/Rotation System

Lab Demo

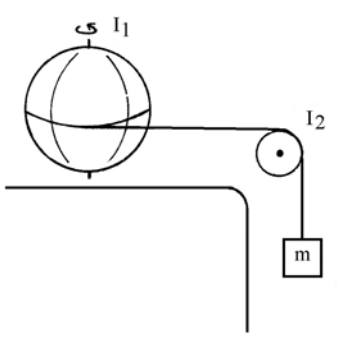
Set up the rotational inertia apparatus about 1.5 m above the floor. Put its two masses at the ends of the rods, balanced. Hang a mass $m_1 \simeq 0.2\,\text{kg}$ on a string from the rotational inertia apparatus.

- 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.

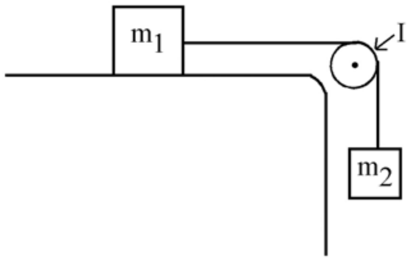


Problems

11.4.1. A uniform spherical shell of radius R=10 cm rotates about a vertical axis on frictionless bearings (see figure). Its rotational inertia about this vertical axis is $I_1 = 0.01\,\text{kg}\cdot\text{m}^2$. A massless cord passes around the equator of the shell, over a pulley of rotational inertia $I_2 = 4.5\times10^{-4}\ \text{kg}\cdot\text{m}^2$ and radius r=3 cm, and is attached to a small object of mass m=0.4 kg. There is no friction on the pulley's axle; the cord does not slip on the pulley. What is the speed of the mass m after it falls h=0.7 m from rest?



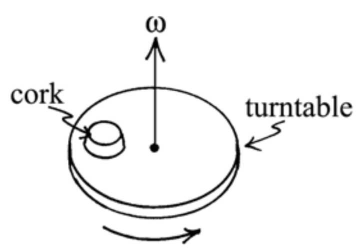
11.4.2. Drawn below is a mass of m_2=2.0 kg hanging on a light string. This string passes over a pulley wheel with I=0.1 kg m^2 and radius R=0.20 m, and then connects to a second mass with m_1=3.0 kg. The coefficients of friction between m_1 and the table are $\mu_s = 0.20$ and $\mu_k = 0.15$. Find the speed of m_2 after it falls from rest 1.0 m.



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?

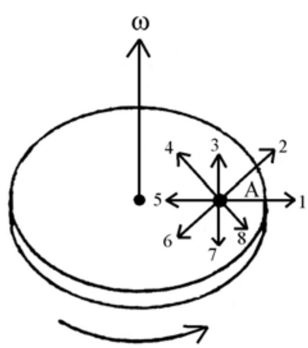


Problems

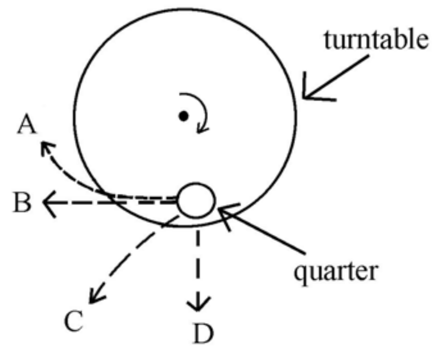
The adjacent figure of a turntable rotating in the counterclockwise direction is relevant for Problems 11.5.1 and 11.5.2. A watermelon seed is placed at a point A on the turntable which rotates along with the disk. Several vectors (numbered 1,2,3,4,5,6,7,8) are drawn at the point A to denote possible direction of the static friction acting on the watermelon seed.

11.5.1. If the disk is rotating with a constant angular velocity ω, which of the vectors best represents the direction of the static friction on the watermelon seed?

11.5.2. If the angular velocity of the disk is increasing with a constant angular acceleration α, which of the vectors best represents the direction of the static friction on the watermelon seed?



11.5.3. A 10 g quarter sits on the edge of a phonograph turntable, which is rotating at 33 1/3 rpm. It does not slip so it remains stationary relative to the turntable. What is the frictional force on the quarter? If the phonograph speed is increased to 45 rpm, the quarter slips off the turntable. The drawing (a view from above) shows the quarter right before it slips off. Which path does it follow, A, B, C or D when it slips?



11.5.4. A phonograph turntable is rotating at 33 1/3 rpm.

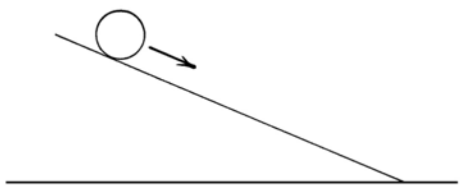
a. What is the *linear speed* (in m/s) of a point on the turntable at a distance of 10 cm from the axis of the turntable?
b. Now suppose that the turntable slows down and stops in 20 sec after the motor is turned off. Find its (uniform) angular acceleration in units of rad/sec^2.
c. Find the magnitude of the radial, tangential and *total* linear acceleration of a point 10 cm from the axis of the turntable, 10 sec after the motor is turned off.

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.



Problems

12.1.1. A small sphere of mass m and radius r, and a small cylinder of same mass m and radius r roll without slipping down an inclined plane making an angle θ with the horizontal. Find the acceleration of each object. What do you conclude from this Demo?

12.1.2. A small sphere of mass m and radius r, and a large sphere of mass M and radius R, roll without slipping down an inclined plane making an angle θ with the horizontal. Find the acceleration of each sphere. What do you conclude from this Demo?

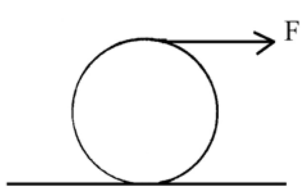
12.1.3. A round object with a rotational inertia of $I = \beta m R^2$, where β is a constant, m is its mass and R is its radius, rolls without slipping a distance ℓ down a plane inclined at an angle θ.

a. If it started from rest, what is its speed?
b. What percentage of its total kinetic energy is rotational?

12.1.4. The wheel drawn below has mass m, radius R and rotational inertia I= m $R^2/2$. A force F is applied to the upper rim as drawn. The wheel rolls without slipping.

a. Find the acceleration of the center of mass of the wheel.
b. Find the frictional force between the wheel and the surface.

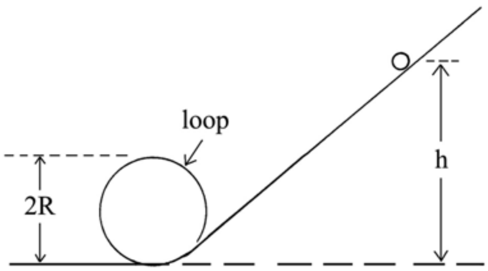
(If you want to think deeply, compare the frictional force directions when the applied force F is on the upper rim, as drawn below, or at the center, and the resulting skids when F is large.)



12.2. Rolling and Circular Motion

Lab Demo

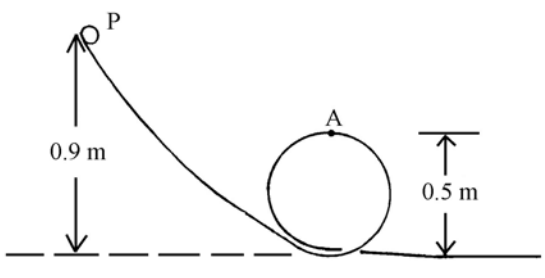
Determine experimentally the minimum height to start a ball (solid sphere) from rest so that it will travel around the loop without leaving the track. Compare this to theory.



Problem

12.2.1. A small steel ball of mass m=0.1 kg and radius r=1.0 cm can *roll* along the loop-the-loop (see figure). The ball starts from point P which is at a height of 0.9 m above the bottom of the loop. The radius R shown in the figure is 0.25 m. Rotational inertia of a sphere about an axis through its center of mass is $(2/5)m\ r^2$.

a. If the ball is released from rest at point P, find the speed of the ball at point A.
b. If the ball is released from rest at point P, find the normal force acting on the ball at point A.
c. Repeat part (a) and (b) for a *block* of mass m=0.1 kg, which slides down a frictionless inclined plane.



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.

Problems

12.3.1. The rotational inertia of a collapsing spinning star changes to one-sixth of its initial value. What is the ratio of its final angular speed ω_f to its initial angular speed ω_i **?** What is the ratio of its new rotational kinetic energy K_f to its initial rotational kinetic energy K_i?

12.3.2. Two children of same mass m=30 kg, are playing on a merry-go-round of rotational inertia $I = 100\ \mathrm{kg} \cdot \mathrm{m}^2$ and radius R=1.50 m. One child is standing on the outer edge of the merry-go-round as it rotates counterclockwise at 5.00 rev/min. The second child, who is on the ground, runs on a path tangent to the edge of the merry-go-round and jumps on to the outer edge of the merry-go-round with speed v.

a. If the second child runs in the same direction as the rotation of the merry-go-round. At what speed must the second child run so that the rotational speed of the merry-go-round is the same after he/she jumps on?
b. Now the second child runs in the opposite direction of the rotation of the merry-go-round. At what speed must the second child run so that the merry-go-round stops after he/she jumps on?

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?

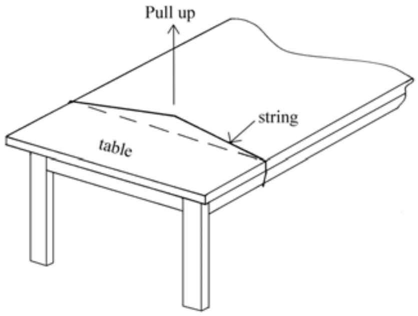
Problem

12.4.1. Consider the studio demonstration quantitatively. A student is sitting on a stool that can rotate freely about a vertical axis. The student, initially at rest, is holding a bicycle wheel whose rotational inertia about its central axis is $1.5\,\mathrm{kg}\cdot\mathrm{m}^2$. The wheel is rotating at an angular speed of 4.0 rev/s. As seen from overhead, the rotation is counterclockwise. The student now inverts the wheel so that, as seen from overhead, it is rotating clockwise. The inversion results in the student and the stool (and of course the wheel's center) rotating together as a rigid body with rotational inertia of $I = 6.1\,\mathrm{kg}\cdot\mathrm{m}^2$ and angular speed ω. Find ω. (By the way, is $I = 6.1\,\mathrm{kg}\bullet\mathrm{m}^2$ a reasonable value?)

13.1. Statics of a Point

Lab Demo

Get some string that is hard to break by hand pulling. Wrap it once tightly 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.

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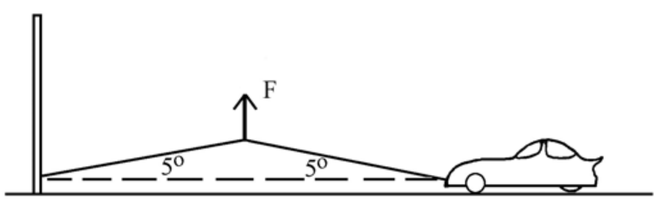
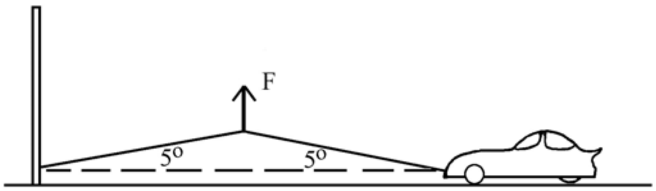
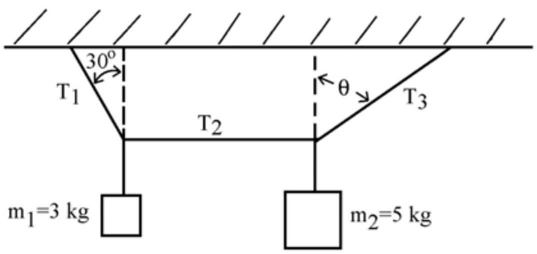


Problems

13.1.1. To get a car out of the mud, a person ties one end of a rope to the car and the other end of the rope to a strong pole. When the person pulls at the midpoint (see figure) with a force of 400 N, the car barely begins to move. What is the magnitude of the force pulling on the car (the tension in the rope)?



13.1.2. If the system shown below is in static equilibrium with the string in the middle horizontal; find the tensions T_1, T_2, T_3 and the angle θ.

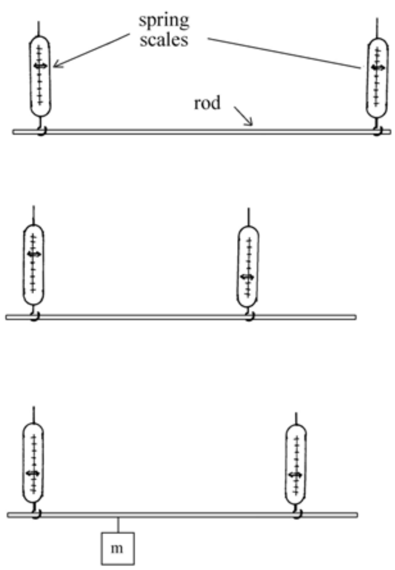


13.2. Statics of an Extended Object

Lab Demo

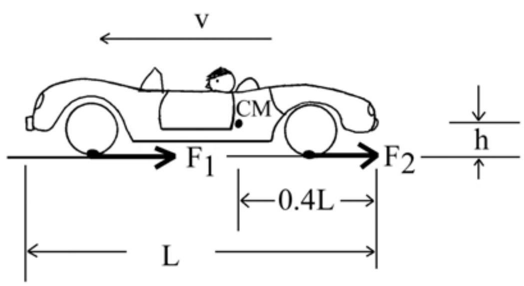
Hang a long rod over the lab table with a spring scale at each end. Keep the scales vertical.

- 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?

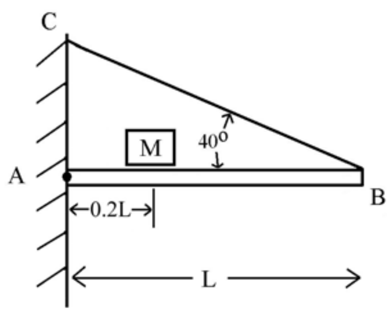


Problems

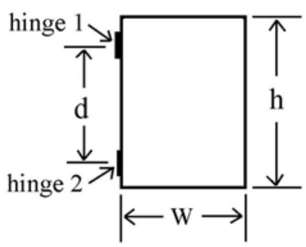
13.2.1. When brakes are applied to a car to slow it down, assume that the frictional force on each front tire is F_1 and the frictional force on each rear tire is F_2. If we demand that the net torque about the car's center of mass (CM) is zero (a good thing to demand), show that F_1 must be greater than F_2.



13.2.2. In the figure AB is a thin, uniform rod of mass m=30 kg and length L hinged at A. BC is a wire and another *mass* M=100 kg is placed on the rod at a distance 0.2L from A. The whole system is in equilibrium. Find the tension in the wire, and the horizontal and vertical components of the force on the rod from the hinge.



13.2.3. A uniform door of mass m, which is h tall and w wide hangs from two hinges placed symmetrically a distance d apart on the door. Each hinge supports half of the weight of the door in the vertical direction. Find the horizontal force (magnitude and direction) of each hinge on the door.

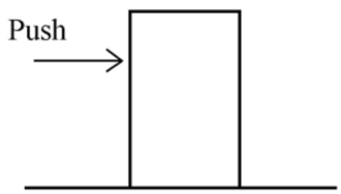


13.3. Tipping Versus Sliding

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?



Problems

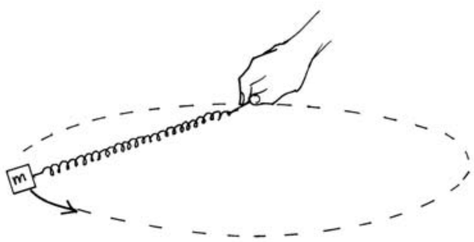
13.3.1. A U-haul van carries a uniform steelcase of mass M, height H, and square cross section of side L. When the van accelerates too fast, the steelcase tips before it slides off. What is the maximum acceleration of the van so that the steelcase does not tip over?

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.



Problem

14.1.1. In studio lab 14.1, the mass m=0.1 kg and the *unperturbed* length of the spring is 20 cm. Compute the time period of the mass when it has a orbit of R=24 cm and R=34 cm. What do you conclude from this Demo? (For example, compare to the fact that Pluto, which is further away from the Sun than Earth, takes about 250 years to go round the Sun!)

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!

Problems

14.3.1. Io and Europa are two well-known moons of Jupiter. The period of Io is 1.77 days and it is at a distance of 422×10^3 km from the center of Jupiter. The period of Europa is 3.55 days. What is Europa's distance from the center of Jupiter? Use these data to find Jupiter's mass.

14.3.2. A *geosynchronous* satellite is one that stays above the same point on the equator of the Earth, i.e., the satellite revolves around the Earth with the same period (1 day) that the Earth rotates on its axis. Such satellites are used in weather forecasting and in communications. What is the distance of such a satellite from the center of the Earth as a fraction of the distance of the Moon from the Earth? Use the fact that the Moon takes 27 days to go around the Earth.

14.3.3. Mars has about 1/10 the mass of Earth, and 1/2 of Earth's diameter. What is the acceleration of a free-falling body near the surface of Mars? (Use SI/metric units for the acceleration; a mix up with the units did lead to the crash of a NASA probe on Mars!)

15.1. Density

Lab Demo

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

Problem

15.1.1. A sphere of lead (density = $13.4 g/cm^3$ = $13{,}400 kg/m^3$) and a sphere of plastic (density=$1.5 g/cm^3$ = $1500 kg/m^3$) each have the same mass.

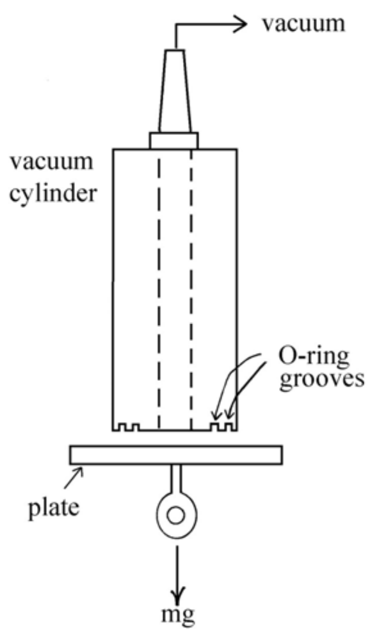
a. What is the ratio of their volumes?
b. What is the ratio of their diameters?

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.

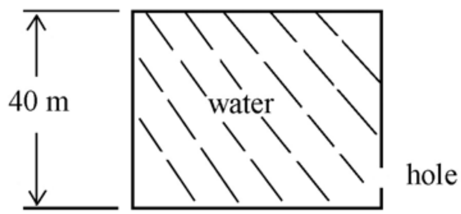
- Hang masses on the plate until the plate falls from the cylinder and record this mass (some leakage may occur so have someone continue pumping). Make sure someone is prepared to catch the masses when they fall.
- Repeat for an O-ring in the other groove. Compare the diameters of the O-rings and the 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?



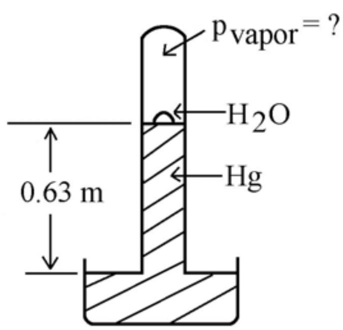
Problems

15.2.1. Many foods are sealed under vacuum. When the container is opened, the lid pops up. If indeed a vacuum is present inside a jar of pickles, what is the force due to the atmosphere (with pressure $p=10^5$ Pa) on the lid of the jar if the diameter of the lid is 8 cm? What mass has this weight?

15.2.2. A large *air-tight* tank 40 m tall and 50 m in diameter is filled completely with water. If a hole is punctured into the tank 5 m above the bottom, to what level below the top of the tank does the water fall before the water stops flowing out of the hole? The atmospheric pressure is 10^5 Pa.



15.2.3. A small amount of water sits on top of the column of mercury in a mercury barometer. On the day when the atmospheric pressure is 0.98×10^5 Pa, the column of mercury stands 0.63 m high. Find the pressure of the water vapor in the space above the mercury column in the barometer. The density of mercury is $13.6 \times 10^3 \mathrm{kg/m^3}$.

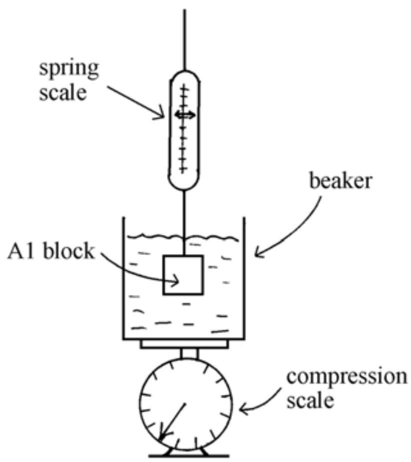


15.3. The Bouyant Force – Archimedes' Principle

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?



Problems

15.3.1. An object weighs 15 pounds. This object is immersed in a container of water that was full to the top, causing water to spill out. Once immersed, the object appears to weigh 5 pounds. What is the weight of the water that spilled out?

15.3.2. A metal object hangs from a spring balance. The balance indicates 30 N in air, 20 N when the object is submerged in water, and 24 N when the object is submerged in an unknown liquid. What is the specific gravity of the unknown liquid?

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?

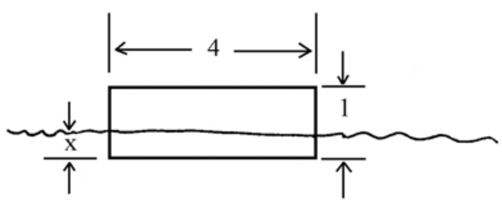
Problems

15.4.1. A beaker is filled to the top with water (density 1000 kg/m^3). Then a block of wood of density 700 kg/m^3 and volume $2\times10^{-4}\,\mathrm{m}^3$ is placed in the water.

a. What is the buoyant force on the wood?
b. What volume of water is displaced over the sides of the beaker?

15.4.2. A large rectangular solid of mass 1000 kg and dimension $4\times2\times1$ meters is floating in a lake with its top and bottom horizontal.

a. What is the buoyant force on the solid?
b. How far below the surface of the water is the bottom of the solid (i.e., what is the distance x shown in the figure)?
c. What is the *gauge pressure* on the bottom of the solid?
d. What is the total force, magnitude and direction, due to this pressure on the bottom of the solid?

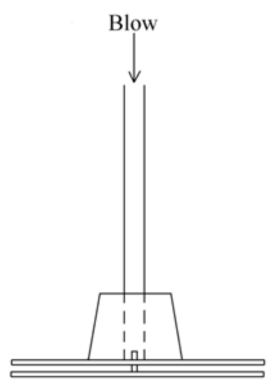


15.4.3. What force must be applied to an aluminum block with mass 30 kg to lift it at constant velocity off the bottom of a swimming pool filled with water. The density of Al is 2700 kg/m^3 and that for water is 1000 kg/m^3.

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?



Problems

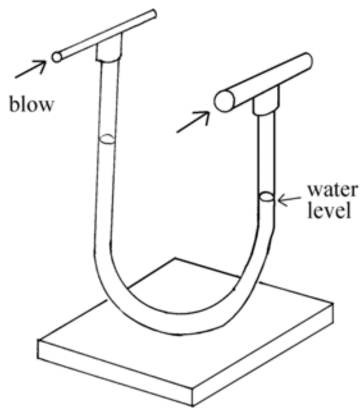
15.5.1. You desire to bring a 4' x 8' (1.2 m × 2.4 m) sheet of plywood home from the hardware store on top of your car on a windless day. What is the maximum speed you can drive before the aerodynamic lift causes the plywood to lift off your car. Assume you lay the sheet level, its mass is 20 kg, and the air speed under the sheet is zero.

15.5.2. What is the aerodynamic force (magnitude and direction) on the door of my Porsche as I drive down the road at 140 mph (65 m/s). Assume no wind and the area of the door is 1.5 m^2.

15.6. The Bernoulli Effect - II

Lab Demo

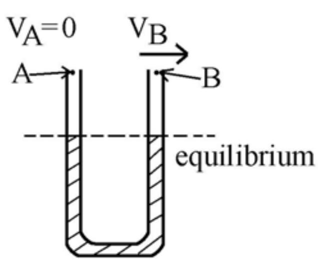
Show that a pressure differential can be developed across the U-tube in the apparatus drawn below. The different sides have different diameters. Does this make a difference? Does the direction of the air flow matter? Test and explain.



Problems

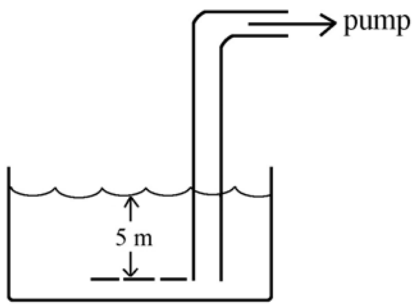
15.6.1. A person blows air with a speed of 20 m/s across the top of one side of a U-tube containing water as drawn in the figure.

a. What is the pressure difference between points A and B just above the open ends of the tube?
b. How far does the water level on side B move from equilibrium (before person blows)? Does it move up or down?



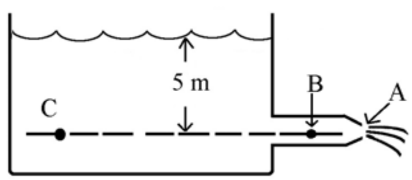
15.6.2. Drawn below is a large tank of water with density 1000 kg/m^3. A pipe of diameter 0.05 m is placed in the tank and its end opens up 5 m below the surface.

a. If there is no fluid flow, what is the gauge pressure (i.e. neglect atmospheric pressure) at the opening of the pipe?
b. If water is now pumped from the pipe at the volume flow rate of 0.01 m^3/s, what is the linear velocity, v, of the fluid in the pipe?
c. What is the pressure at the opening of the pipe when this pump is on?



15.6.3. A large tank of water drawn in the figure has a pipe of diameter 10 cm connected a depth of d=5 m below the surface. The pipe terminates in an orifice A of diameter 6 cm.

a. Find the velocity of the water as it emerges from the hole at point A.
b. Find the gauge pressure at point B.
c. Find the gauge pressure at point C (far from the pipe).



16.1. Spring-Mass Oscillations

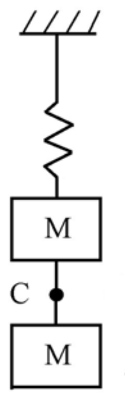
Lab Demo

- 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.

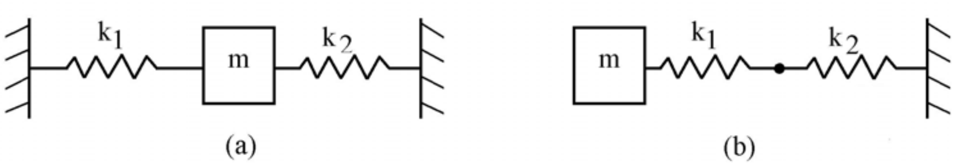
Problems

16.1.1. A spring with force constant k=100 N/s has two, M=1.0 kg masses hanging from it as drawn. The system is motionless until the string between the two masses is cut at point C and the lower mass falls to the floor.

a. Find the period of the remaining oscillator (with only one M=1.0 kg mass remaining).
b. Find the amplitude of the motion.
c. Find the maximum velocity of the 1.0kg mass during the oscillation.

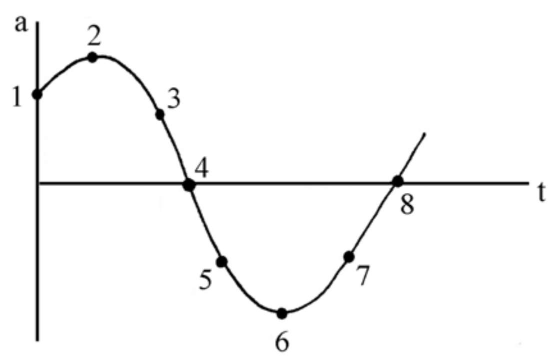


16.1.2. What are the *effective* spring constants k_{eff} and periods of oscillations for the spring-mass systems shown below in figures (a) and (b)? Here k_1=10 N/m, k_2=20 N/m, and m=0.2 kg.



Refer to the adjacent graph of acceleration a(t) versus time t of a particle undergoing a simple harmonic motion for the following questions.

16.1.3. a. Which of the labeled points correspond to the particle at $+x_m$?
(i) 1 (ii) 2 (iii) 4 (iv) 6 (v) 8
b. At point 8, the velocity of the particle is:
(i) positive (ii) negative (iii) zero
c. At point 3, the particle is at:
(i) $-x_m$
(ii) $+x_m$
(iii) between $-x_m$ and 0
(iv) between 0 and $+x_m$
d. At what point(s) is the velocity a maximum?



16.2. The Simple Pendulum

Lab Demo

Hang a mass m from a string of length ℓ.

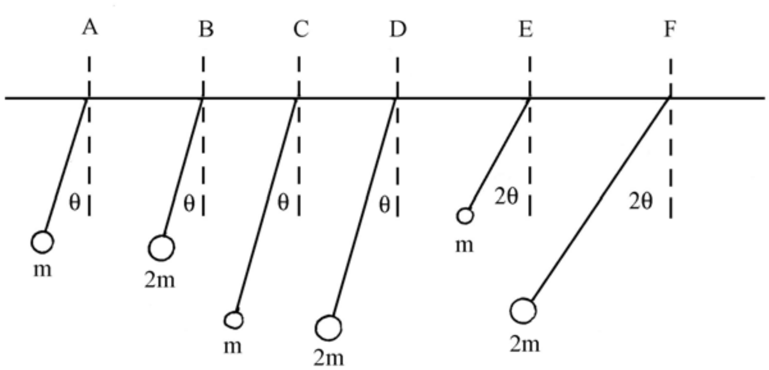
- Set it oscillating and determine the functionality of the period T with mass, length ℓ and amplitude. How might you plot T vs. ℓ to achieve a linear graph?
- From your measurements and theory, determine g.

Problems

16.2.1. What is the time period of a simple pendulum 1.5 m long in (a) an elevator accelerating upward at a rate of 1.5 m/s^2, (b) an elevator accelerating downward at a rate of 1.5 m/s^2, (c) an elevator accelerating upward at a rate of 9.8 m/s^2, (d) an elevator accelerating downward at a rate of 9.8 m/s^2, (e) in free fall?

16.2.2. The acceleration due to gravity g varies from place to place over the Earth's surface. In city A, g=9.80 m/s^2. When a pendulum clock, which is accurate in city A, is taken from city A to city B, it is found to *lose* 2.5 min/day. What is the value of g in city B?

16.2.3. Drawn below are a number of pendulum oscillators with lengths of either 1 m or 2 m shown at their maximum displacement. Rank them in order of increasing period, smaller period (fastest) first. If some are equal, indicate so.

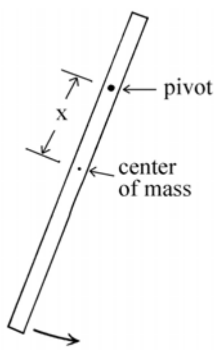


16.3. The Physical Pendulum

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.



Problem

16.3.1. Measurement of the time period of a physical pendulum is an easy way to figure out the rotational inertia I of an extended object, even if that object is *non-uniform*. Suppose we take a nonuniform stick of mass 0.3 kg whose center of mass is at a distance of 40 cm from one end (can easily be found by balancing the stick). When pivoted about that end the stick oscillates with a time period of 2.0 sec.

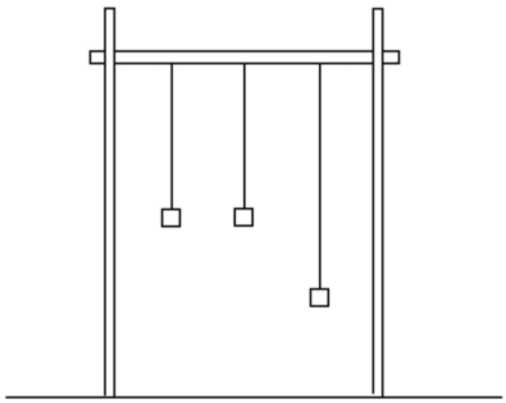
a. What is the rotational inertia of the stick about an axis passing through the pivot and perpendicular to the stick?
b. What is the rotational inertia parallel to this axis but through the center of mass?

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)?

Problems

17.1.1. The equation of a transverse wave on a string is

$$y = (0.10 \text{ m}) \sin [(20 \text{ m}^{-1}) x - (6 \text{ s}^{-1}) t].$$

The tension in the string is 20 N. Find (a) the wave speed and (b) the linear density of the material of the string.

17.1.2. A sinusoidal wave is traveling on a string. A small tag is attached to the string at x=20 cm. The tag is found to oscillate with time according to the equation

$$y (20 \text{ cm}, t) = (10.0 \text{ cm}) \sin [1.5 - (6 \text{ s}^{-1}) t].$$

a. What is the *speed of the wave* traveling along the string?
b. What is the maximum (transverse) speed of the tag?

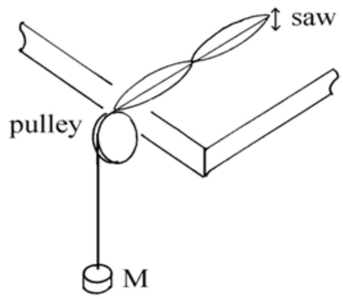
17.1.3. A string oscillates according to the equation

$$y = (0.10 \text{ m}) \sin [(20 \text{ m}^{-1} x] \cos [(6 \text{ s}^{-1}) t].$$

a. What kind of waves does this equation represent?
b. What are the amplitude and the speed of the two waves (which are identical except for direction of travel) whose superposition leads to this functional form for the oscillation?
c. What is the distance between antinodes?

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.

Problems

17.2.1. A string, fastened at both ends, has a length of 2.5 m and is oscillating as a four-loop standing wave with an amplitude of 5.0 cm.

a. What is the wavelength λ of the standing wave?
b. The wave speed in the string is 120 m/s. What is the frequency of this oscillation?
c. What is the fundamental frequency?

17.2.2. Standing waves are formed in a string of length L, fastened at both ends. A node is found at a point located L/3 from one end. What are the possible harmonic numbers of the standing wave? If the fundamental frequency is 250 Hz, what are the frequencies of the above harmonics?

17.2.3. Standing waves are formed in a string of length L, fastened at both ends. For two successive resonances, the wavelength is 0.60m for the n-th harmonic, and 0.48m for the n+1-th harmonic. Find n and L.

17.2.4. Standing waves are formed in a string of length 2.5 m, fastened at both ends. For two successive resonances, the frequencies are 440 Hz and 550 Hz.

a. What is the fundamental (first harmonic) frequency?
b. Draw the fundamental mode of vibration. What is its wavelength?
c. Draw the 440 Hz mode. What is its wavelength?

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.

Problems

17.3.1. Consider standing waves in organ pipes of length L open at both ends.

a. How are the symmetry and boundary conditions of these standing waves different from standing waves in a string of length L fastened at both ends?
b. Draw the first four harmonics in each case.
c. Compare the expression for the frequency of various harmonics for these two cases.

17.3.2. Consider standing waves in organ pipes of length L open at one end and closed at the other end.

a. How are the symmetry and boundary conditions of these standing waves different from standing waves in a string of length L fastened at one end?
b. Draw the first four harmonics in each case.
c. Compare the expression for the frequency of various harmonics for these two cases.

17.3.3. Why does no one care about organ pipes closed at both ends?

17.3.4. Organ pipe X is open at both ends and is twice as long as organ pipe Y which is open at one end. The ratio of their 3rd harmonics $f_{3,X}/f_{3,Y}$ is given by:

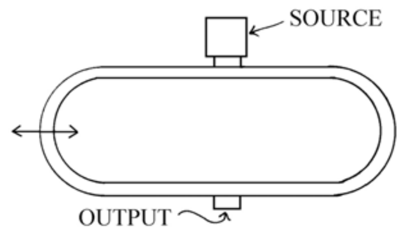
(i) 3:5
(ii) 5:3
(ii) 1:1
(iv) 1:2
(v) 2:1

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.

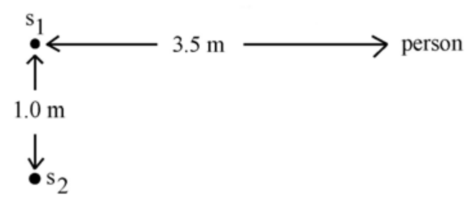
- From this calculate the sound wavelength.
- Then calculate the speed of sound.



Problems

18.1.1. Two loudspeakers S_1 and S_2 are 1.0 m apart. A person stands 3.5 m straight out from one loudspeaker and detects completely destructive interference. The frequency of the emitted sound wave is 1024 Hz from each speaker and the speed of sound in air is 343 m/s. Find the distance of the person from the other speaker, if:

a. the speakers are emitting sound waves in phase with each other, or
b. the speakers are emitting sound waves completely out of phase with each other.

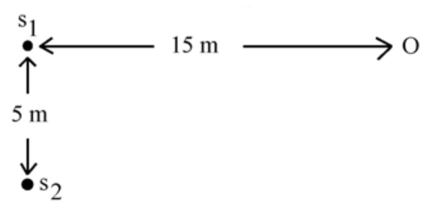


18.1.2. Two sound sources S_1 and S_2 are driven in phase. They are 5.0m apart. An observer O is 15.0 m straight out from S_2, as drawn. As the sound frequency is increased from very low, the observer hears the total sound at O decrease until no sound is heard. Assume that the speed of sound is 340 m/s.

a. At what lowest frequency is no sound heard at O?

After that, the frequency is continuously increased until a maximum in intensity is heard.

b. At what frequency is this maximum heard?
c. If, while at this maximum, one of the speakers is disconnected so that sound is only emitted from the other speaker, by what factor, if any, does the sound intensity change? (Be sure to indicate increase or decrease as well as factor).



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.

Problems

18.3.1. a. An ambulance with speed 25 m/s and with a siren emitting sound wave of 1200 Hz is trying to overtake a cyclist pedaling a bike at 3 m/s. What frequency does the cyclist hear?
b. What frequency would the cyclist hear after the ambulance overtakes and passes the cyclist?

18.3.2. The Doppler effect can be useful in various medical diagnostic techniques. Consider a simple example of measuring the speed of blood flow. If the medical technician uses an ultrasonic transmitter of frequency 5.5 MHz and measures a beat frequency of 2.29 KHz between the direct sound wave sent along the blood flow direction and the sound wave reflected from moving blood cells, what is the speed of blood flow? Assume that the speed of sound in blood is 1440 m/s (this number is the speed of sound in water.).

19.1. Thermal Expansion

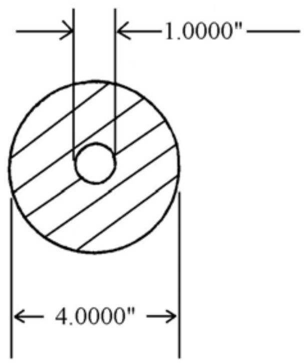
Lab Demo

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

Problems

19.1.1. A steel disk with a center hole is carefully machined to the specifications as shown in the figure. The dimensions are at 20^{o}C. If the coefficient of linear expansion for steel is α(steel)=11 $\times 10^{-6}$ K^{-1}, compute the following when the temperature rises to 40^{o}C:

a. The outer diameter of the disk.
b. The diameter of the hole.
c. The fractional change $\Delta d/d$ of both the diameters of the hole and the disk.
d. The fractional change, $\Delta V/V$, of the volume of the disk.



19.1.2. A rod is measured to be exactly 20.00 cm long using a steel ruler at 20^{o}C. *Both* rod and ruler are heated in an oven to 270^{o}C and now the rod measures 20.10 cm by this ruler. Find the coefficient of linear expansion for the rod material. The coefficient of linear expansion for steel is α(steel)=11 $\times$ 10^{-6} K^{-1}.

19.1.3. A simple pendulum is made of a brass wire attached to a 1kg brass sphere. The distance from the pendulum's support to the center of the sphere is 1.0 m at 20^{o}C. Find the fractional change in the frequency of the pendulum (i.e. df/f where f=1/T and T is the time period of the pendulum) for a 1^{o}C increase in the temperature (linear expansion for brass is α=19 $\times$ 10^{-6} K^{-1}).

19.1.4. A uniform cylinder of glass with cross sectional area A=4000 cm^2 is filled with ethanol to a height of h=10.000 cm at 20^{o}C. The linear expansion coefficient of glass is 10^{-5} K^{-1}, and the volume expansion coefficient of ethanol is 5 $\times$ 10^{-5} K^{-1}.

a. What is the volume of ethanol at 20^{o}C?
b. What is the volume of the ethanol at 60^{o}C?
c. To what height does the level of ethanol reach in the cylinder at 60^{o}C?

19.2. Mechanical Equivalent of Heat

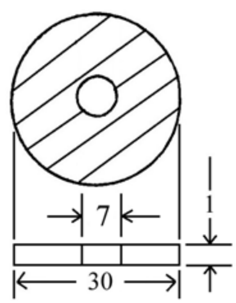
Lab Demo

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.

Problem

19.2.1. A 1000 kg Fiat 124 Spider decelerates from v=40 m/s to zero in 4 sec on a level ground. The four disk brakes absorb all the mechanical energy in the form of heat, each brake absorbing the same amount of energy. The brakes are annuli with inner diameter of 7 cm, outer diameter of 30 cm, and 1 cm thick (see drawing). They are made out of steel with a density 7.9 grams/cm^3 and specific heat 0.12 cal/grams^{o}C. Find the change in temperature of a brake disk from when v=40 m/s to when the car has stopped.



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 $T \simeq 100^{o}C$. 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.

Problem

19.4.1. Consider two objects A and B having the same mass m. The specific heat of object B is twice that of the object A. Initially A is at 300 K and B is at 450 K. They are placed in thermal contact and the combination is isolated. What is the final temperature of both objects?

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?

Problems

19.5.1. Mass m of steam at 100^{o}C is mixed with 100 grams of ice at –15^{o}C. The final temperature of the mixture is 40^{o}C. Find m. The specific heat of ice is 0.53 cal/grams^{o}C.

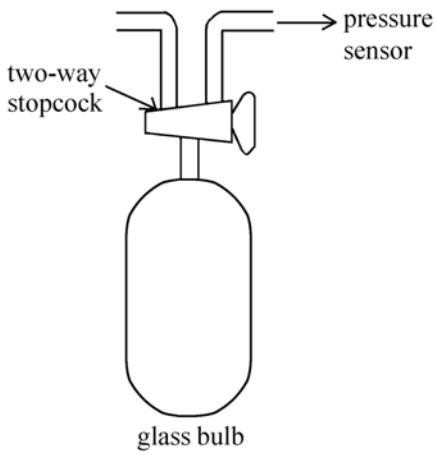
19.5.2. 10 grams of liquid lead (Pb) at 400^{o}C is poured into 40 grams of water, initially at 20^{o}C. Equilibrium is attained at 30^{o}C. The specific heats are: c(liquid Pb)=0.12 cal/grams^{o}C, c(solid Pb)= 0.09 cal/grams^{o}C, c(water)=1.0 cal/grams^{o}C. The melting point of lead is 327^o C. Find the latent heat of fusion for lead.

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 $p \to 0$? According to your data where does this happen?

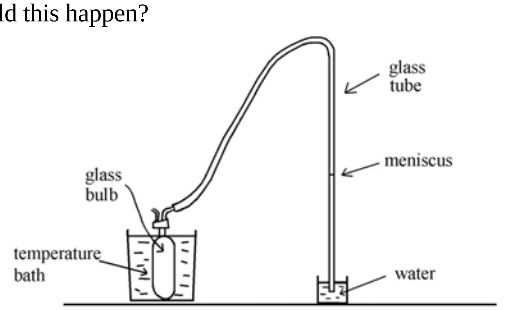


20.2. Ideal Gas—Charles's Law (V vs. T)

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?).

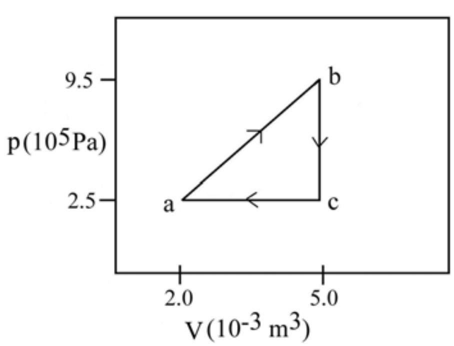
- Now move the bulb to room temperature water, and then ice water, with equilibrium established at each. Measure the temperatures and the height h of the water meniscus in the tube as the contracting gas sucks up the water. (Oops! Can gases suck?)
- From these data calculate the change in volume with 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 $V \to 0$. According to your data, where would this happen?



Problem

20.2.1. A sample of an ideal gas is taken through the cyclic process *abca* shown in the figure. At point *a*, T= 200^{o}C.

a. What is the temperature of the gas at point *c*?
b. How many moles of gas are there?
c. How much heat was added to the gas during the cycle *abca*?



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.

<u>Operation</u>:

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.

Problems

20.3.1. a) What is the rms velocity of a N_2 molecule in air at 25^oC. b) What is the rms velocity of a pollen particle with diameter $5\mu m$ and density $1.2 g/cm^3$ suspended in air at 25^oC?

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.

Problems

20.4.1. One mole of an ideal diatomic gas expands adiabatically. Its temperature changes from 600^oC to 40^oC.

a. What is the change in internal energy?
b. How much work is done?

20.4.2. 95^oF air just above a Kansas wheat field rushes upward into the center of a thunderstorm supercell to an altitude of 40,000 feet where it has expanded to ¾ of its original density. Since the expansion was relatively fast for such a large air mass, it can be assumed to be adiabatic. What is the air temperature at 40,000 feet?