4. Context-rich Problems

What Are Context Rich Problems?

Context-rich problems are designed to encourage students to use an organized, logical problem-solving strategy instead of their novice, formula-driven, "plug-and-chug" strategy. Specifically, context rich problems are designed to encourage students to (a) consider physics concepts in the context of real objects in the real world; (b) view problem-solving as a series of decisions; and (c) use the fundamental concepts of physics to qualitatively analyze a problem *before* the mathematical manipulation of formulas.

Consequently, **all** context-rich problems have the following characteristics:

- Each problem is a short story in which the major character is the student. That is, each problem statement uses the personal pronoun "you."
- The problem statement includes a plausible motivation or reason for "you" to calculate something.
- The objects in the problems are real (or can be imagined) -- the idealization process occurs explicitly.
- No pictures or diagrams are given with the problems. Students must visualize the situation by using their own experiences.
- The problem cannot be solved in one step by plugging numbers into a formula.

These characteristics emphasize the need for students to make decisions by using their physics knowledge. They encourage students to view physics problem-solving as something that they can do successfully and imagine doing in their future careers. They discourage the view that problem solving in physics is a purely mathematical exercise with no real-world applications for the average person.

What Are The Characteristics of a Good Group Problem?

Group problems should be more difficult to solve than easy problems typically given on an individual test. But the increased difficulty should be primarily conceptual, not mathematical. Difficult mathematics is best accomplished by individuals, not by groups. So problems that involve long, tedious mathematics but little physics, or problems that require the use of a shortcut or "trick" that only experts would be likely to know do not make good group problems. In fact, the best group problems involve the straight-forward application of the fundamental principles (e.g., the definition of velocity and acceleration, the independence of motion in the vertical and horizontal directions) rather than the repeated use of derived formulas (e.g., $v_f^2 - v_o^2 = 2ad$).

Twenty-one Characteristics That Can Make a Problem More Difficult

There are twenty-one characteristics of a problem that can make it more difficult to solve than a standard textbook exercise:

Approach

1 Cues Lacking

A. No explicit target variable. The unknown variable of the problem is not explicitly stated.

B. Unfamiliar context. The context of the problem is very unfamiliar to the students (e.g., cosmology, molecules).

2 Agility with Principles

A. Choice of useful principles. The problem has more than one possible set of useful concepts that could be applied for a correct solution.

B. Two general principles. The correct solution requires students to use two major principles (e.g., torque and linear kinematics).

C. Very abstract principles. The central concept in the problem is an abstraction of another abstract concept. (e.g., potential, magnetic flux).

3 Non-standard Application

A. Atypical situation. The setting, constraints, or complexity is unusual compared with textbook problems.

B. Unusual target variable. The problem involves an atypical target variable when compared with homework problems.

Analysis of Problem

4 Excess or Missing Information

A. Excess numerical data. The problem statement includes more data than is needed to solve the problem.

B. Numbers must be supplied. The problem requires students to either remember or estimate a number for an unknown variable.

C. Simplifying assumptions. The problem requires students to generate a simplifying assumption to eliminate an unknown variable.

5 Seemingly Missing Information

A. Vague statement. The problem statement introduces a vague, new mathematical statement.

B. Special conditions or constraints. The problem requires students to generate information from their analysis of the conditions or constraints.

C. Diagrams. The problem requires students to extract information from a spatial diagram.

6 Additional Complexity

A. More than two subparts. The problem solution requires students decompose the problem into more than two subparts.

B. Five or more terms per equation. The problem involves five or more terms in a principle equation (e.g., three or more forces acting along one axes on a single object).

C. Two directions (vector components). The problem requires students to treat principles (e.g., forces, momentum) as vectors.

Mathematical Solution

7 Algebra Required

A. No numbers. The problem statement does not use any numbers.

B. Unknown(s) cancel. Problems in which an unknown variable, such as a mass, ultimately factors out of the final solution.

C. Simultaneous equations. A problem that requires simultaneous equations for a solution.

8 Targets Math Difficulties

A. Calculus or vector algebra. The solution requires the students to sophisticated vector algebra, such as cross products, or calculus.

B. Lengthy or Detailed Algebra. A successful solution to the problem is not possible without working through lengthy or detailed algebra (e.g., a messy quadratic equation).

BEWARE! Good group problems are difficult to construct because they can easily be made too complex and difficult to solve. A good group problem does not have **all** of the above difficulty characteristics, but usually only *2- 5* of these characteristics.

How to Create Context-rich Group Problems

One way to invent context-rich problems is to start with a textbook exercise or problem, then modify the problem. You may find the following steps helpful:

1. If necessary, determine a context (real objects with real motions or interactions) for the textbook exercise or problem. You may want to use an unfamiliar context for a **very** difficult group problem.

2. Decide on a motivation -- Why would anyone want to calculate something in this context?

3. Determine if you need to change the target variable to

   (a) make the problem more than a one-step exercise, or

   (b) make the target variable fit your motivation.

5. Determine if you need to change the given information (or target variable) to make the problem an application of fundamental principles (e.g., the definition of velocity or acceleration) rather than a problem needing the application of many derived formulas.

4. Write the problem like a short story.

5. Decide how many "difficulty" characteristics (characteristics that make the problem more difficult) you want to include, then do some of the following:
   (a) think of an unfamiliar context; or use an atypical setting or target variable;
   (b) think of different information that could be given, so two approaches (e.g., kinematics *and* forces) would be needed to solve the problem instead of one approach (e.g., forces), or so that more than one approach could be taken
   (c) write the problem so the target variable is not explicitly stated;
   (d) determine extra information that someone in the situation would be likely to have; or leave out common-knowledge information (e.g., the boiling temperature of water);
   (e) depending on the context, leave out the explicit statement of some of the problem idealizations (e.g., change "massless rope" to "very light rope"); or remove some information that students could extract from an analysis of the situation;
   (f) take the numbers out of the problem and use variable names only;
   (g) think of different information that could be given, so the problem solution requires the use of vector components, geometry/trigonometry to eliminate an unknown, or calculus.

6. Check the problem to make sure it is solvable, the physics is straight-forward, and the mathematics is reasonable. After you have written the problem, solve it yourself and use the judging strategy (next section) to determine its difficulty.

Some common contexts include:

- physical work (pushing, pulling, lifting objects vertically, horizontally, or up ramps)
- suspending objects, falling objects
- sports situations (falling, jumping, running, throwing, etc. while diving, bowling, playing golf, tennis, football, baseball, etc.)
- situations involving the motion of bicycles, cars, boats, trucks, planes, etc.
- astronomical situations (motion of satellites, planets)
- heating and cooling of objects (cooking, freezing, burning, etc.)

Sometimes it is difficult to think of a motivation. We have used the following motivations:

- You are . . . . (in some everyday situation) and need to figure out . . . .
- You are watching . . . . (an everyday situation) and wonder . . . .
- You are on vacation and observe/notice . . . . and wonder . . . .
- You are watching TV or reading an article about . . . . and wonder . . .
- Because of your knowledge of physics, your friend asks you to help him/her . . . .
- You are writing a science-fiction or adventure story for your English class about . . . . and need to figure out . . . .
- Because of your interest in the environment and your knowledge of physics, you are a member of a Citizen's Committee (or Concern Group) investigating . . . .
- You have a summer job with a company that . . . . Because of your knowledge of physics, your boss asks you to . . . .
- You have been hired by a College research group that is investigating . . . . Your job is to determine . . . .
- You have been hired as a technical advisor for a TV (or movie) production to make sure the science is correct. In the script . . . ., but is this correct?
- When really desperate, you can use the motivation of an artist friend designing a kinetic sculpture!

Decision Strategy for Judging Problems

Outlined below is a decision strategy to help you decide whether a context-rich problem is a good individual test problem, group practice problem, or group test problem.

1. *Read* the problem statement. *Draw* the diagrams and *determine* the equations needed to solve the problem (through plan-a-solution step).

2. *Reject* if:
    - the problem can be solved in one step,
    - the problem involves long, tedious mathematics, but little physics; or

- the problem can only be solved easily using a "trick" or shortcut that only experts would be likely to know. (In other words, the problem should be a straight-forward application of fundamental concepts and principles.)

3. *Check* for the twenty-one characteristics that make a problem more difficult:

___ unfamiliar context
___ very abstract principles
___ two general principles
___ more than two subparts
___ no explicit target variable
___ excess information
___ atypical situation
___ vague statement
___ diagrams
___ no numbers
___ calculus or vector algebra
___ numbers must be supplied
___ assumptions needed
___ vector components
___ lengthy algebra
___ simultaneous eqs.
___ choice of useful principles
___ unusual target variable
___ special conditions
___ five or more terms
___ unknowns cancel

4. *Decide* if the problem would be a good group practice problem (20 - 25 minutes), a good group test problem (45 - 50 minutes), or a good (easy, medium, difficult) individual test problem, depending on three factors: (a) the complexity of mathematics, (b) the timing (when problem is to be given to students), and (c) the number of difficulty characteristics of the problem:

Type of Problem	Timing	Diff. Ch.
Group Practice Problems should be shorter and mathematically easier than group test problems.	just introduced to concept(s) just finished study of concept(s)	2 - 3 3 - 4
Group Test Problems can be more complex mathematically.	just introduced to concept(s) just finished study of concept(s)	3 - 4 4 - 5
Individual Problems can be easy, medium-difficult, or difficult: Easy	just introduced to concept(s) just finished study of concept(s)	0 -1 1 - 2
Medium-difficult	just introduced to concept(s) just finished study of concept(s)	1 - 2 2 - 3
Difficult	just introduced to concept(s) just finished study of concept(s)	2 - 3 3 - 4

There is considerable overlap in the criteria, so most problems can be judged to be **both** a good group practice or test problem *and* a good easy, medium-difficult, or difficult individual problem.

Problems in This Booklet

Most of the context-rich problems in this booklet were group and individual test problems given in the algebra-based introductory physics courses and the calculus-based courses at the University of Minnesota. The problems vary greatly in length and difficulty. The more difficult problems were usually given as cooperative group problems. The problems also vary in quality. Feel free to edit, revise, and improve them!

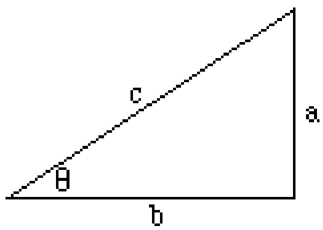
To discourage memorization and focus students' attention on the fundamental concepts necessary to solve the problems, the tests include all equations and constants necessary to solve the problems. No other equations are allowed to appear in the students solutions unless explicitly derived from the given equations. These equations represent the fundamental concepts taught in the courses. A few new equations are added for each successive test, so the information available is the accumulation from the beginning of the course. The next two pages contain the mathematical and physics accumulated at the end of the algebra-based course and the calculus based course. All of the problems in this section can be solved with the equations on these sheets.

The context-rich problems in this booklet are grouped according to the fundamental concepts and principle(s) required for a solution (instead of the typical textbook chapter or topic organization): linear kinematics problems, force problems, force with linear kinematics, force and circular motion, conservation problems.

Equations: One-Semester Algebra-based Course

This is a closed book, closed notes exam. Calculators are permitted. The only formulas and constants which may be used in this exam are those given below. You may, of course, derive any expressions you need from those that are given. If in doubt, ask. Define all symbols and justify all mathematical expressions used. Make sure to state all of the assumptions used to solve a problem. Each problem is worth 25 points.

Useful Mathematical Relationships:



For a right triangle: $\sin\theta = \frac{a}{c}$, $\cos\theta = \frac{b}{c}$, $\tan\theta = \frac{a}{b}$,

$a^2 + b^2 = c^2,\ \sin^2\theta + \cos^2\theta = 1$

For a circle: $C = 2\pi R$, $A = \pi R^2$

For a sphere: $A = 4pR^2$, $V = \frac{4}{3}\ pR^3$

If $Ax^2 + Bx + C = 0$, then $x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

Fundamental Concepts:

$$\bar{v}_r = \frac{?r}{?t}$$

$$\bar{a}_r = \frac{?v_r}{?t}$$

$$v_r = \lim(?t \to 0)\frac{?r}{?t}$$

$$a_r = \lim(?t \to 0)\frac{?v_r}{?t}$$

$$\Sigma F_r = ma_r$$

$$\Delta E_{system} = E_{transfer}$$

$$E_{transfer} = \Sigma F_r\, ?r$$

$$KE = \frac{1}{2}\, mv^2$$

$$P = \frac{E_{transfer}}{?t}$$

$$\Delta p_{r\ system} = p_{r\ transfer}$$

$$p_r = mv_r$$

$$p_{r\ transfer} = \Sigma F_r\, ?t$$

$$I = \frac{?q}{?t}$$

Under Certain Conditions:

$$\bar{v}_r = \frac{(v_{ir} + v_{fr})}{2}$$

$$a = \frac{v^2}{r}$$

$$F = \mu_k F_N$$

$$F = \mu_s F_N$$

$$F = k?r$$

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = \frac{k_e q_1 q_2}{r^2}$$

$$PE = mgy$$

$$PE = \frac{1}{2}\, kx^2$$

$$PE = -\frac{Gm_1m_2}{r}$$

$$PE = \frac{k_e q_1 q_2}{r}$$

$$\Delta E_{internal} = c\, m\, \Delta T$$

$$\Delta E_{internal} = m\, L$$

$$V_E = \frac{PE}{q}$$

$$V = IR$$

$$P = IV$$

$$R = \frac{\rho L}{A}$$

Useful constants: 1 mile = 5280 ft, 1 ft = 0.305 m, $g = 9.8\ m/s^2 = 32\ ft/s^2$, 1 lb = 4.45 N, $G = 6.7 \times 10^{-11}\ N\ m^2/kg^2$, $k_e = 9.0 \times 10^9\ N\ m^2 / C^2$, $e = 1.6 \times 10^{-19}\ C$

Equations: Two-Semester Calculus-based Course

Useful Mathematical Relationships:

For a circle: $C = 2\pi R$, $A = \pi R^2$; For a sphere: $A = 4\pi R^2$, $V = \frac{4}{3}\pi R^3$

$\frac{d(z^n)}{dz} = nz^{n-1}$, $\frac{d(\cos z)}{dz} = -\sin z$, $\frac{d(\sin z)}{dz} = \cos z$, $\frac{df(z)}{dt} = \frac{df(z)}{dz}\frac{dz}{dt}$, $\int(\frac{dw}{dz})dz = w$,

$\frac{d}{dz}\int(w)dz = w$, $\int(z^n)dz = \frac{z^{n+1}}{n+1}$ $(n \neq -1)$, $\int\frac{1}{\left(a^2+z^2\right)^{\frac{3}{2}}}dz = \frac{z}{a^2\left(a^2+z^2\right)^{\frac{1}{2}}}$

Fundamental Concepts and Principles:

$\vec{v} = \frac{d\vec{r}}{dt}$ $\quad s = \frac{dr}{dt}$ $\quad \vec{a} = \frac{d\vec{v}}{dt}$ $\quad \omega = \frac{d\theta}{dt} = \frac{v_t}{r}$ $\quad \alpha = \frac{d\omega}{dt} = \frac{a_t}{r}$ $\quad a_r = \frac{v^2}{r}$

$\sum\vec{F} = m\vec{a}$ $\quad \vec{\tau} = \vec{r}\times\vec{F}$ $\quad \sum\vec{\tau} = I\vec{\alpha}$ $\quad KE = \frac{1}{2}mv^2$ $\quad E_f - E_i = \Delta E_{transfer}$ $\quad \vec{p} = m\vec{v}$

$\vec{p}_f - \vec{p}_i = \Delta\vec{p}_{transfer}$ $\quad \vec{p}_{transfer} = \int\vec{F}dt$ $\quad \vec{r}_{cm} = \frac{\sum_i m_i\vec{r}_i}{\sum_i m_i} = \frac{\int_{object}\vec{r}dm}{\int_{object}dm}$ $\quad I = \sum_i m_i r_i^2 = \int_{object} r^2 dm$ $\quad \vec{L} = I\vec{\omega}$

$\vec{L} = \vec{r}\times\vec{p}$ $\quad \vec{L}_{transfer} = \int\vec{\tau}dt$ $\quad \vec{L}_f - \vec{L}_i = \Delta\vec{L}_{transfer}$ $\quad f = \frac{1}{T}$ $\quad \omega = 2\pi f$

$\vec{E} = \frac{\vec{F}_e}{q}$ $\quad P = \frac{dE}{dt}$ $\quad I = \frac{dq}{dt}$ $\quad P = I\Delta V$ $\quad k_e = \frac{1}{4\pi\varepsilon_o}$ $\quad C = \frac{Q}{\Delta V}$

$\oiint\vec{E}\bullet d\vec{A} = \frac{Q}{\varepsilon_o}$ $\quad \oiint\vec{B}\bullet d\vec{A} = 0$ $\quad \oiint\vec{\Gamma}\bullet d\vec{A} = 4\pi Gm$ $\quad \iint_{surface}\vec{E}\bullet d\vec{A} = \Phi$ $\quad \iint_{surface}\vec{B}\bullet d\vec{A} = \Phi$ $\quad \mu = IA$

Under Certain Conditions:

$x_f = \frac{1}{2}a_x(\Delta t)^2 + v_{ox}\Delta t + x_o$ $\quad F = \mu_k F_N$ $\quad F \leq \mu_s F_N$ $\quad F = -kx$ $\quad KE = \frac{1}{2}I\omega^2$ $\quad PE = mgy$ $\quad PE = \frac{1}{2}kx^2$

$\theta_f = \frac{1}{2}\alpha(\Delta t)^2 + \omega_o\Delta t + \theta_o$ $\quad y = A\cos(2\pi ft + \partial)$ $\quad I = I_{cm} + Md^2$ $\quad E_{transfer} = \int\vec{F}\bullet d\vec{\ell}$

$\Delta E_{internal} = cm\Delta T$ $\quad \Delta E_{internal} = mL$ $\quad \vec{F} = -G\frac{m_1m_2}{r^2}\hat{r}$ $\quad U = -G\frac{m_1m_2}{r}$ $\quad \vec{F} = k\frac{q_1q_2}{r^2}\hat{r}$

$\vec{E} = k\frac{q}{r^2}\hat{r}$ $\quad U = k_e\frac{q_1q_2}{r}$ $\quad \Delta V = \frac{\Delta U}{q}$ $\quad R = \rho\frac{L}{A}$ $\quad \Delta V = IR$

$\vec{F} = q\vec{v}\times\vec{B}$ $\quad \oint\vec{B}\bullet d\vec{s} = \mu_o I$ $\quad \vec{\tau} = \vec{\mu}\times\vec{B}$ $\quad \varepsilon = -\frac{d\Phi}{dt}$

Useful constants: 1 mile = 5280 ft, 1km = 5/8 mile, g = 9.8 m/s^2 = 32 ft/s^2 , 1 cal = 4.2 J,
R_E = 4x10^3 miles, G = 6.7x10^{-11} Nm^2/kg^2, k_e = 9.0 x 10^9 Nm^2/C^2, e = 1.6 x 10^{-19} C,
μ_o = 4p x 10^{-7} T m/A

Linear Kinematics Problems

The problems in this section can be solved with the application of the kinematics relationships. The problems are divided into five groups according to the type of motion of the object(s) in the problem: (1) one-dimensional motion at a constant velocity; (2) one-dimensional motion at a constant acceleration; (3) one-dimensional motion, both constant velocity and constant acceleration, (4) two-dimensional (projectile) motion, and (5) two-dimensional motion, both constant velocity and constant acceleration.

One-dimensional, Constant Velocity

1. You are writing a short adventure story for your English class. In your story, two submarines on a secret mission need to arrive at a place in the middle of the Atlantic ocean at the same time. They start out at the same time from positions equally distant from the rendezvous point. They travel at different velocities but both go in a straight line. The first submarine travels at an average velocity of 20 km/hr for the first 500 km, 40 km/hr for the next 500 km, 30 km/hr for the next 500 km and 50 km/hr for the final 500 km. In the plot, the second submarine is required to travel at a constant velocity, so the captain needs to determine the magnitude of that velocity.

2. It is a beautiful weekend day and, since winter will soon be here, you and four of your friends decide to spend it outdoors. Two of your friends just want to relax while the other two want some exercise. You need some quiet time to study. To satisfy everyone, the group decides to spend the day on the river. Two people will put a canoe in the river and just drift downstream with the 1.5 mile per hour current. The second pair will begin at the same time as the first from 10 miles downstream. They will paddle upstream until the two canoes meet. Since you have been canoeing with these people before, you know that they will have an average velocity of 2.5 miles per hour relative to the shore when they go against this river current. When the two canoes meet, they will come to shore and you should be there to meet them with your van. You decide to go to that spot ahead of time so you can study while you wait for your friends. Where will you wait?

3. It's a sunny Sunday afternoon, about 65 °F, and you are walking around Lake Calhoun enjoying the last of the autumn color. The sidewalk is crowded with runners and walkers. You notice a runner approaching you wearing a tee-shirt with writing on it. You read the first two lines, but are unable to read the third and final line before he passes. You wonder, "Hmm, if he continues around the lake, I bet I'll see him again, but I should anticipate the time when we'll pass again." You look at your watch and it is 3:07 p.m. You recall the lake is 3.4 miles in circumference. You estimate your walking speed at 3 miles per hour and the runner's speed to be about 7 miles per hour.

4. You have joined the University team racing a solar powered car. The optimal average speed for the car depends on the amount of sun hitting its solar panels. Your job is to determine strategy by programming a computer to calculate the car’s average speed for a day consisting of different race conditions. To do this you need to determine the equation for the day’s average speed based on the car’s average speed for each part of the trip. As practice you imagine that the day’s race consists of some distance under bright sun, the same distance with partly cloudy conditions, and twice that distance under cloudy conditions. 5.

5. Because of your technical background, you have been given a job as a student assistant in a University research laboratory that has been investigating possible accident avoidance systems for oil tankers. Your group is concerned about oil spills in the North Atlantic caused by a super tanker running into an

iceberg. The group has been developing a new type of down-looking radar which can detect large icebergs. They are concerned about its rather
short range of 2 miles. Your research director has told you that the radar signal travels at the speed of light which is 186,000 miles per second but once the signal arrives back at the ship it takes the computer 5 minutes to process the signal. Unfortunately, the super tankers are such huge ships that it takes a long time to turn them. Your job is to determine how much time would be available to turn the tanker to avoid a collision once the tanker detects an iceberg. A typical sailing speed for super tankers during the winter on the North Atlantic is about 15 miles per hour. Assume that the tanker is heading directly at an iceberg that is drifting at 5 miles per hour in the same direction that the tanker is going.

The following three problems are mathematically equivalent, with different contexts.

6. You and your friend run outdoors at least 10 miles every day no matter what the weather (well almost). Today the temperature is at a brisk 0 ^{o}F with a -20 ^{o}F wind chill. Your friend, a real running fanatic, insists that it is OK to run. You agree to this madness as long as you both begin at your house and end the run at her nice warm house in a way that neither of you has to wait in the cold. You know that she runs at a very consistent pace with an average speed of 3.0 m/s, while your average speed is a consistent 4.0 m/s. Your friend finishes warming up first so she can get a head start. The plan is that she will arrive at her house first so that she can unlock the door before you arrive. Five minutes later, you notice that she dropped her keys. If she finishes her run first she will have to stand around in the cold and will not be happy. How far from your house will you be when you catch up to her if you leave immediately, run at your usual pace, and don't forget to take her keys?

7. Because of your technical background, you have been given a job as a student assistant in a University research laboratory that has been investigating possible accident avoidance systems for automobiles. You have just begun a study of how bats avoid obstacles. In your study, a bat is fitted with a transceiver that broadcasts the bats velocity to your instruments. Your research director has told you that the signal travels at the speed of light which is 1.0 ft/nanosecond (1 nanosecond is 10^{-9} seconds). You know that the bat detects obstacles by emitting a forward going sound pulse (sonar) which travels at 1100 ft/s through the air. The bat detects the obstacle when the sound pulse reflect from the obstacle and that reflected pulse is heard by the bat. You are told to determine the maximum amount of time that a bat has after it detects the existence of an obstacle to change its flight path to avoid the obstacle. In the experiment your instruments tell you that a bat is flying straight toward a wall at a constant velocity of 20.0 ft/s and emits a sound pulse when it is 10.0 ft from the wall.

8. You have been hired to work in a University research laboratory assisting in experiments to determine the mechanism by which chemicals such as aspirin relieve pain. Your task is to calibrate your detection equipment using the properties of a radioactive isotope (an atom with an unstable nucleus) which will later be used to track the chemical through the body. You have been told that your isotope decays by first emitting an electron and then, some time later, it emits a photon which you know is a particle of light. You set up your equipment to determine the time between the electron emission and the photon emission. Your apparatus detects both electrons and photons. You determine that the electron and photon from a decay arrive at your detector at the same time when it is 2.0 feet from your radioactive sample. A previous experiment has shown that the electron from this decay travels at one half the speed of light. You know that the photon travels at the speed of light which is 1.0 foot per nanosecond. A nanosecond is 10^{-9} seconds.

One Dimensional, Constant Acceleration

9. You are part of a citizen's group evaluating the safety of a high school athletic program. To help judge the diving program you would like to know how fast a diver hits the water in the most complicated dive. The coach has his best diver perform for your group. The diver, after jumping from the high board, moves through the air with a constant acceleration of 9.8 m/s^2. Later in the dive, she passes near a lower diving board which is 3.0 m above the water. With your trusty stop watch, you determine that it took 0.20 seconds to enter the water from the time the diver passed the lower board. How fast was she going when she hit the water?

10. As you are driving to school one day, you pass a construction site for a new building and stop to watch for a few minutes. A crane is lifting a batch of bricks on a pallet to an upper floor of the building. Suddenly a brick falls off the rising pallet. You clock the time it takes for the brick to hit the ground at 2.5 seconds. The crane, fortunately, has height markings and you see the brick fell off the pallet at a height of 22 meters above the ground. A falling brick can be dangerous, and you wonder how fast the brick was going when it hit the ground. Since you are taking physics, you quickly calculate the answer.

11. Because of your knowledge of physics, and because your best friend is the third cousin of the director, you have been hired as the assistant technical advisor for the associate stunt coordinator on a new action movie being shot on location in Minnesota. In this exciting scene, the hero pursues the villain up to the top of a bungee jumping apparatus. The villain appears trapped but to create a diversion she drops a bottle filled with a deadly nerve gas on the crowd below. The script calls for the hero to quickly strap the bungee cord to his leg and dive straight down to grab the bottle while it is still in the air. Your job is to determine the length of the unstretched bungee cord needed to make the stunt work. The hero is supposed to grab the bottle before the bungee cord begins to stretch so that the stretching of the bungee cord will stop him gently. You estimate that the hero can jump off the bungee tower with a maximum velocity of 10 ft/sec. straight down by pushing off with his feet and can react to the villain's dropping the bottle by strapping on the bungee cord and jumping in 2 seconds.

12. You are helping a friend devise some challenging tricks for the upcoming Twin Cities Freestyle Skateboard Competition. To plan a series of moves, he needs to know the rate that the skateboard, with him on board, slows down as it coasts up the competition ramp which is at 30° to the horizontal. Assuming that this rate is constant, you decide to have him conduct an experiment. When he is traveling as fast as possible on his competition skateboard, he stops pushing and coasts up the competition ramp. You measure that he typically goes about 95 feet in 6 seconds. Your friend weighs 170 lbs. wearing all of his safety gear and the skateboard weighs 6 lbs.

13. You have a summer job working for a University research group investigating the causes of the ozone depletion in the atmosphere. The plan is to collect data on the chemical composition of the atmosphere as a function of the distance from the ground using a mass spectrometer located in the nose cone of a rocket fired vertically. To make sure the delicate instruments survive the launch, your task is to determine the acceleration of the rocket before it uses up its fuel. The rocket is launched straight up with a constant acceleration until the fuel is gone 30 seconds later. To collect enough data, the total flight time must be 5.0 minutes before the rocket crashes into the ground.

One Dimensional, Constant Velocity and Constant Acceleration

14. You have landed a summer job as the technical assistant to the director of an adventure movie shot here in Minnesota. The script calls for a large package to be dropped onto the bed of a fast moving pick-up truck from a helicopter that is hovering above the road, out of view of the camera. The helicopter is 235 feet above the road, and the bed of the truck is 3 feet above the road. The truck is traveling down the road at 40 miles/hour. You must determine when to cue the assistant in the helicopter to drop the package so it lands in the truck. The director is paying $20,000 per hour for the chopper, so he wants you to do this successfully in one take.

15. Just for the fun of it, you and a friend decide to enter the famous Tour de Minnesota bicycle race from Rochester to Duluth and then to St. Paul. You are riding along at a comfortable speed of 20 mph when you see in your mirror that your friend is going to pass you at what you estimate to be a constant 30 mph. You will, of course, take up the challenge and accelerate just as she passes you until you pass her. If you accelerate at a constant 0.25 miles per hour each second until you pass her, how long will she be ahead of you?

16. In your new job, you are the technical advisor for the writers of a gangster movie about Bonnie and Clyde. In one scene Bonnie and Clyde try to flee from one state to another. (If they got across the state line, they could evade capture, at least for a while until they became Federal fugitives.) In the script, Bonnie is driving down the highway at 108 km/hour, and passes a concealed police car that is 1 kilometer from the state line. The instant Bonnie and Clyde pass the patrol car, the cop pulls onto the highway and accelerates at a constant rate of 2 m/s^2. The writers want to know if they make it across the state line before the pursuing cop catches up with them.

17. The University Skydiving Club has asked you to plan a stunt for an air show. In this stunt, two skydivers will step out of opposite sides of a stationary hot air balloon 5,000 feet above the ground. The second skydiver will leave the balloon 20 seconds after the first skydiver but you want them both to land on the ground at the same time. The show is planned for a day with no wind so assume that all motion is vertical. To get a rough idea of the situation, assume that a skydiver will fall with a constant acceleration of 32 ft/sec^2 before the parachute opens. As soon as the parachute is opened, the skydiver falls with a constant velocity of 10 ft/sec. If the first skydiver waits 3 seconds after stepping out of the balloon before opening her parachute, how long must the second skydiver wait after leaving the balloon before opening his parachute?

18. Because parents are concerned that children are learning "wrong" science from TV, you have been asked to be a technical advisor for a science fiction cartoon show on Saturday morning. In the plot, a vicious criminal (Natasha Nogood) escapes from a space station prison. The prison is located between galaxies far away from any stars. Natasha steals a small space ship and blasts off to meet her partners somewhere in deep space. The stolen ship accelerates in a straight line at its maximum possible acceleration of 30 m/sec^2. After 10 minutes all of the fuel is burned up and the ship coasts at a constant velocity. Meanwhile, the hero (Captain Starr) learns of the escape while dining in the prison with the warden's daughter (Virginia Lovely). Of course he immediately (as soon as he finishes dessert) rushes off the recapture Natasha. He gives chase in an identical ship, which has an identical maximum acceleration, going in an identical direction. Unfortunately, Natasha has a 30 minute head start. Luckily, Natasha's ship did not start with a full load of fuel. With his full load of fuel, Captain

Starr can maintain maximum acceleration for 15 minutes. How long will it take Captain Starr's ship to catch up to Natasha's?

19. Because parents are concerned that children are learning "wrong" science from TV, you have been asked to be a technical advisor for a new science fiction show. The show takes place on a space station at rest in deep space far away from any stars. In the plot, a vicious criminal (Alicia Badax) escapes from the space station prison. Alicia steals a small space ship and blasts off to meet her partners somewhere in deep space. If she is to just barely escape, how long do her partners have to transport her off her ship before she is destroyed by a photon torpedo from the space station? In the story, the stolen ship accelerates in a straight line at its maximum possible acceleration of 30 m/sec^2. After 10 minutes (600 seconds) all of the fuel is burned and the ship coasts at a constant velocity. Meanwhile, the hero of this episode (Major Starr) learns of the escape while dining with the station's commander. Of course she immediately rushes off to fire photon torpedoes at Alicia. Once fired, a photon torpedo travels at a constant velocity of 20,000 m/s. By that time Alicia has a 30 minute (1800 seconds) head start on the photon torpedo.

20. You want to visit your friend in Seattle over Winter-quarter break. To save money, you decide to travel there by train. But you are late finishing your physics final, so you are late in arriving at the train station. You run as fast as you can, but just as you reach one end of the platform your train departs, 30 meters ahead of you down the platform. You can run at a maximum speed of 8 m/s and the train is accelerating at 1 m/s. You can run along the platform for 50 meters before you reach a barrier. Will you catch your train?

21. Because of your knowledge of physics, you have been assigned to investigate a train wreck between a fast moving passenger train and a slower moving freight train both going in the same direction. You have statements from the engineer of each train and the stationmaster as well as some measurements which you make. To check the consistency of each person's description of the events leading up to the collision, you decide to calculate the distance from the station that the collision should have occurred if everyone were telling what really happened and compare that with the actual position of the wreck which is 0.5 miles from the station. In this calculation you decide that you can ignore all reaction times. Here is what you know:
    - The stationmaster claims that she noted that the freight train was behind schedule. As regulations require, she switched on a warning light just as the last car of the freight train passed her.
    - The freight train engineer says he was going at a constant speed of 10 miles per hour.
    - The passenger train engineer says she was going at the speed limit of 40 miles per hour when she approached the warning light. Just as she reached the warning light she saw it go on and immediately hit the brakes.
    - The warning light is located so that a train gets to it 2.0 miles before it gets to the station.
    - The passenger train slows down at a constant rate of 1.0 mile per hour for each minute as soon as you hit the brakes.

    DO ONLY THE PROBLEM SOLVING STEPS NECESSARY TO FOCUS THE PROBLEM AND DESCRIBE THE PHYSICS OF THE PROBLEM. DO **NOT** SOLVE THIS PROBLEM.

Two Dimensional, Constant Acceleration (Projectile Motion)

22. While on a vacation to Kenya, you visit the port city of Mombassa on the Indian Ocean. On the coast you find an old Portuguese fort probably built in the 16th century. Large stone walls rise vertically from the shore to protect the fort from cannon fire from pirate ships. Walking around on the ramparts, you find the fort's cannons mounted such that they fire horizontally out of holes near the top of the walls facing the ocean. Leaning out of one of these gun holes, you drop a rock which hits the ocean 3.0 seconds later. You wonder how close a pirate ship would have to sail to the fort to be in range of the fort's cannon? Of course you realize that the range depends on the velocity that the cannonball leaves the cannon. That muzzle velocity depends, in turn, on how much gunpowder was loaded into the cannon.
    (a) Calculate the muzzle velocity necessary to hit a pirate ship 300 meters from the base of the fort.
    (b) To determine how the muzzle velocity must change to hit ships at different positions, make a graph of horizontal distance traveled by the cannonball (range) before it hits the ocean as a function of muzzle velocity of the cannonball for this fort.

23. Because of your knowledge of physics, you have been hired as a consultant for a new James Bond movie, "Oldfinger". In one scene, Bond jumps horizontally off the top of a cliff to escape a villain. To make the stunt more dramatic, the cliff has a horizontal ledge a distance h beneath the top of the cliff which extends a distance L from the vertical face of the cliff. The stunt coordinator wants you to determine the minimum horizontal speed, in terms of L and h, with which Bond must jump so that he misses the ledge.

24. You are on the target range preparing to shoot a new rifle when it occurs to you that you would like to know how fast the bullet leaves the gun (the muzzle velocity). You bring the rifle up to shoulder level and aim it horizontally at the target center. Carefully you squeeze off the shot at the target which is 300 feet away. When you collect the target you find that your bullet hit 9.0 inches below where you aimed.

25. You have a great summer job working on the special effects team for a Minnesota movie, the sequel to Fargo. A body is discovered in a field during the fall hunting season and the sheriff begins her investigation. One suspect is a hunter who was seen that morning shooting his rifle horizontally in the same field. He claims he was shooting at a deer and missed. You are to design the "flashback" scene which shows his version of firing the rifle and the bullet kicking up dirt where it hits the ground. The sheriff later finds a bullet in the ground. She tests the hunter's rifle and finds the velocity that it shoots a bullet (muzzle velocity). In order to satisfy the nitpickers who demand that movies be realistic, the director has assigned you to calculate the distance from the hunter that this bullet should hit the ground as a function of the bullet's muzzle velocity and the rifle's height above the ground.

26. The Minneapolis Police Department has hired you as a consultant in a robbery investigation. A thief allegedly robbed a bank in the IDS Crystal Court. To escape the pursing security guards, the thief took the express elevator to the roof of the IDS tower. Then, in order to not be caught with the evidence, she allegedly threw the money bag to a waiting accomplice on the roof of Dayton's, which is just to the west of the IDS tower (they are separated by the Nicollet Mall). The defense attorney contends that in order to reach the roof of Dayton's, the defendant would have had to throw the money bag with a minimum horizontal velocity of 10 meters/second. But in a test, she could throw the bag with a maximum velocity of no more than 5 meters/second. How will you advise the prosecuting attorney? You determine that he IDS tower is 250 meters high, Dayton's is 100 meters high and the Mall is 20 meters wide.

27. You are watching people practicing archery when you wonder how fast an arrow is shot from a bow. With a flash of insight you remember your physics and see how you can easily determine what you want to know by a simple measurement. You ask one of the archers to pull back her bow string as far as possible and shoot an arrow horizontally. The arrow strikes the ground at an angle of 86 degrees from the vertical at 100 feet from the archer.

28. You read in the newspaper that rocks from Mars have been found on Earth. Your friend says that the rocks were shot off Mars by the large volcanoes there. You are skeptical so you decide to calculate the magnitude of the velocity that volcanoes eject rocks from the geological evidence. You know the gravitational acceleration of objects falling near the surface of Mars is only 40% that on the Earth. You assume that you can look up the height of Martian volcanoes and find some evidence of the distance rocks from the volcano hit the ground from pictures of the Martian surface. If you assume the rocks farthest from a volcano were ejected at an angle of 45 degrees, what is the magnitude of the rock's velocity as a function of its distance from the volcano and the height of the volcano for the rock furthest from the volcano?

29. Watching the world series (only as an example of physics in action), you wonder about the ability of the catcher to throw out a base runner trying to steal second. Suppose a catcher is crouched down behind the plate when he observes the runner breaking for second. After he gets the ball from the pitcher, he throws as hard as necessary to second base without standing up. If the catcher throws the ball at an angle of 30 degrees from the horizontal so that it is caught at second base at about the same height as that catcher threw it, how much time does it take for the ball to travel the 120 feet from the catcher to second base?

30. Because of your physics background, you have been hired as a consultant for a new movie about Galileo. In one scene, he climbs up to the top of a tower and, in frustration over the people who ridicule his theories, throws a rock at a group of them standing on the ground. The rock leaves his hand at 30° from the horizontal. The script calls for the rock to land 15 m from the base of the tower near a group of his detractors. It is important for the script that the rock take precisely 3.0 seconds to hit the ground so that there is time for a good expressive close-up. The set coordinator is concerned that the rock will hit the ground with too much speed causing cement chips from the plaza to injure one of the high priced actors. You are told to calculate that speed.

31. Tramping through the snow this morning, you were wishing that you were not here taking this test. Instead, you imagined yourself sitting in the Florida sun watching winter league softball. You have had baseball on the brain ever since the Twins actually won the World Series. One of the fielders seems very impressive. As you watch, the batter hits a low outside ball when it is barely off the ground. It looks like a home run over the left center field wall which is 200 ft from home plate. As soon as the left fielder sees the ball being hit, she runs to the wall, leaps high, and catches the ball just as it barely clears the top of 10 ft high wall. You estimate that the ball left the bat at an angle of 30^{o}. How much time did the fielder have to react to the hit, run to the fence, and leap up to make the catch ?

32. You are still a member of a citizen's committee investigating safety in the high school sports program. Now you are interested in knee damage to athletes participating in the long jump (sometimes called the broad jump). The coach has her best long jumper demonstrate the event for you. He runs down the track and, at the take-off point, jumps into the air at an angle of 30 degrees from the horizontal. He

comes down in a sand pit at the same level as the track 26 feet away from his take-off point. With what velocity (both magnitude and direction) did he hit the ground?

33. In your new job, you are helping to design stunts for a new movie. In one scene the writers want a car to jump across a chasm between two cliffs. The car is driving along a horizontal road when it goes over one cliff. Across the chasm, which is 1000 feet deep, is another road at a lower height. They want to know the minimum value of the speed of the car so that it does not fall into the chasm. They have not yet selected the car so they want an expression for the speed of the car, v, in terms of the car's mass, m, the width of the chasm, w, and the height of the upper road, h, above the lower road. The stunt director will plug in the actual numbers after a car is purchased.

34. Your friend has decided to make some money during the next State Fair by inventing a game of skill that can be installed in the Midway. In the game as she has developed it so far, the customer shoots a rifle at a 5.0 cm diameter target falling straight down. Anyone who hits the target in the center wins a stuffed animal. Each shot would cost 50 cents. The rifle would be mounted on a pivot 1.0 meter above the ground so that it can point in any direction at any angle. When shooting, the customer stands 100 meters from where the target would hit the ground if the bullet misses. At the instant that the bullet leaves the rifle (with a muzzle velocity of 1200 ft/sec according to the manual), the target is released from its holder 7.0 meters above the ground. Your friend asks you to try out the game which she has set up on a farm outside of town. Before you fire the gun you calculate where you should aim.

35. You have a summer job with an insurance company and have been asked to help with the investigation of a tragic "accident." When you visit the scene, you see a road running straight down a hill which has a slope of 10 degrees to the horizontal. At the bottom of the hill, the road goes horizontally for a very short distance becoming a parking lot overlooking a cliff. The cliff has a vertical drop of 400 feet to the horizontal ground below where a car is wrecked 30 feet from the base of the cliff. Was it possible that the driver fell asleep at the wheel and simply drove over the cliff? After looking pensive, your boss tells you to calculate the speed of the car as it left the top of the cliff. She reminds you to be careful to write down all of your assumptions so she can evaluate the applicability of the calculation to this situation. Obviously, she suspects foul play.

36. You have a summer job with an insurance company and have been asked to help with the investigation of a tragic "accident." When you visit the scene, you see a road running straight down a hill which has a slope of 10 degrees to the horizontal. At the bottom of the hill, the road goes horizontally for a very short distance becoming a parking lot overlooking a cliff. The cliff has a vertical drop of 400 feet to the horizontal ground below where a car is wrecked 30 feet from the base of the cliff. The only witness claims that the car was parked on the hill, he can't exactly remember where, and the car just began coasting down the road. He did not hear an engine so he thinks that the driver was drunk and passed out knocking off his emergency brake. He remembers that the car took about 3 seconds to get down the hill. Your boss drops a stone from the edge of the cliff and, from the sound of it hitting the ground below, determines that it takes 5.0 seconds to fall to the bottom. After looking pensive, she tells you to calculate the car's average acceleration coming down the hill based on the statement of the witness and the other facts in the case. She reminds you to be careful to write down all of your assumptions so she can evaluate the applicability of the calculation to this situation. Obviously, she suspects foul play.

37. Your group has been selected to serve on a citizen's panel to evaluate a new proposal to search for life on Mars. On this unmanned mission, the lander will leave orbit around Mars falling through the

atmosphere until it reaches 10,000 meters above the surface of the planet. At that time a parachute opens and takes the lander down to 500 meters. Because of the possibility of very strong winds near the surface, the parachute detaches from the lander at 500 meters and the lander falls freely through the thin Martian atmosphere with a constant acceleration of 0.40g for 1.0 second. Retrorockets then fire to bring the lander to a softly to the surface of Mars. A team of biologists has suggested that Martian life might be very fragile and decompose quickly in the heat from the lander. They suggest that any search for life should begin at least 9 meters from the base of the lander. This biology team has designed a probe which is shot from the lander by a spring mechanism in the lander 2.0 meters above the surface of Mars. To return the data, the probe cannot be more than 11 meters from the bottom of the lander. Combining the data acquisition requirements with the biological requirements the team designed the probe to enter the surface of Mars 10 meters from the base of the lander. For the probe to function properly it must impact the surface with a velocity of 8.0 m/s at an angle of 30 degrees from the vertical. Can this probe work as designed?

38. You have been hired as a technical consultant for a new action movie. The director wants a scene in which a car goes up one side of an open drawbridge, leaps over the gap between the two sides of the bridge, and comes down safely on the other side of the bridge. This drawbridge opens in the middle by increasing the angle that each side makes with the horizontal by an equal amount. The director wants the car to be stopped at the bottom of one side of the bridge and then accelerate up that side in an amount of time which will allow for all the necessary dramatic camera shots. He wants you to determine the necessary constant acceleration as a function of that time, the gap between the two sides of the open bridge, the angle that the side of the open bridge makes with the horizontal, and the mass of the car.

Two Dimensional, Constant Velocity and Constant Acceleration

The following three problems have a very unfamiliar contexts.

39. You are sitting in front of your TV waiting for the World Series to begin when your mind wanders. You know that the image on the screen is created when electrons strike the screen which then gives off light from that point. In the first TV sets, the electron beam was moved around the screen to make a picture by passing the electrons between two parallel sheets of metal called electrodes. Before the electrons entered the gap between the electrodes, which deflect the beam vertically, the electrons had a velocity of 1.0×10^6 m/s directly toward the center of the gap and toward the center of the screen. Each electrode was 5.0 cm long (direction the electron was going), 2.0 cm wide and the two were separated by 0.5 cm. A voltage was applied to the electrodes which caused the electrons passing between them to have a constant acceleration directly toward one of the electrodes and away from the other. After the electrons left the gap between the electrodes they were not accelerated and they continued until they hit the screen. The screen was 15 cm from the end of the electrodes. What vertical electron acceleration between the electrodes would be necessary to deflect the electron beam 20 cm from the center of the screen?
DO ONLY THE PROBLEM SOLVING STEPS NECESSARY TO FOCUS THE PROBLEM AND DESCRIBE THE PHYSICS OF THE PROBLEM. DO **NOT** SOLVE THIS PROBLEM.

40. You have a summer job in the cancer therapy division of a hospital. This hospital treats cancer by hitting the cancerous region with high energy protons using a machine called a cyclotron. When the beam of protons leaves the cyclotron it is going at a constant velocity of 0.50 the speed of light. You

are in charge of deflecting the beam so it hits the patient. This deflection is accomplished by passing the proton beam between two parallel, flat, high voltage (HV) electrodes which have a length of 10 feet in the entering beam direction. Initially the beam enters the HV region going parallel to the surface of the electrodes. Each electrode is 1 foot wide and the two electrodes are separated by 1.5 inches of very good vacuum. A high voltage is applied to the electrodes so that the protons passing between have a constant acceleration directly toward one of the electrodes and away from the other electrode. After the protons leave the HV region between the plates, they are no longer accelerated during the 200 feet to the patient. You need to deflect the incident beam 1.0 degrees in order to hit the patient. What magnitude of acceleration between the plates is necessary to achieve this deflection angle of 1.0 degree between the incident beam and the beam leaving the HV region? The speed of light is 1.0 foot per nanosecond
(1 ft /(10^{-9} sec)).
DO ONLY THE PROBLEM SOLVING STEPS NECESSARY TO FOCUS THE PROBLEM, DESCRIBE THE PHYSICS OF THE PROBLEM, AND PLAN A SOLUTION. DO **NOT** SOLVE THIS PROBLEM.

41. You have a summer job as an assistant in a University research group that is designing a devise to sample atmospheric pollution. In this devise, it is useful to separate fast moving ions from slow moving ones. To do this the ions are brought into the device in a narrow beam so that all of the ions are going in the same direction. The ion beam then passes between two parallel metal plates. Each plate is 5.0 cm long, 4.0 cm wide and the two plates are separated by 3.0 cm. A high voltage is applied to the plates causing the ions passing between them to have a constant acceleration directly toward one of the plates and away from the other plate. Before the ions enter the gap between the plates , they are going directly toward the center of the gap parallel to the surface of the plates. After the ions leave the gap between the plates, they are no longer accelerated during the 50 cm journey to the ion detector. Your boss asks you to calculate the magnitude of acceleration between the plates necessary to separate ions with a velocity of 100 m/s from those in the beam going 1000 m/s by 2.0 cm?

Force Problems

The problems in this section can be solved with the application of Newton's Laws of Motion. The problems are divided into four groups: (1) linear acceleration, no force components required for solution; (2) linear acceleration, force components required for solution; (3) no acceleration ($a = 0$), no force components required for solution; and (4) no acceleration ($a = 0$), force components required for solution. The specific types of forces involved in a problem (e.g., human push or pull, tension, normal, weight, friction, gravitational, electric) are indicated in bold type at the beginning of each problem.

Linear Acceleration, No Force Components

1. **Tension, Weight:** PLAN THE SOLUTION FOR THE FOLLOWING PROBLEM. An artist friend of yours wants your opinion of his idea for a new kinetic sculpture. The basic concept is to balance a heavy object with two lighter objects using two very light pulleys, which are essentially frictionless, and lots of string. The sculpture has one pulley hanging from the ceiling by a string attached to its center. Another string passes over this pulley. One end of this string is attached to a 25 lb object while the other supports another pulley at its center. This second pulley also has a string passing over it with one end attached to a 10 lb object and the other to a 15 lb object. Your friend hasn't quite figured out the rest of the sculpture but wants to know if, ignoring the mass of the pulley and string, the 25 lb object will remain stationary during the time that the 10 and 15 lb objects are accelerating. DO NOT SOLVE THE PROBLEM.

2. **Weight, Normal:** You have always been impressed by the speed of the elevators in the IDS building in Minneapolis (especially compared to the one in the Physics building). You wonder about the maximum acceleration for these elevators during normal operation, so you decide to measure it by using your bathroom scale. While the elevator is at rest on the ground floor, you get in, put down your scale, and stand on it. The scale reads 130 lbs. You continue standing on the scale when the elevator goes up, carefully watching the reading. During the trip to the 50th floor, the greatest scale reading was 180 lbs.

3. **Tension, Weight:** You have been hired to design the interior of a special executive express elevator for a new office building. This elevator has all the latest safety features and will stop with an acceleration of g/3 in case of any emergency. The management would like a decorative lamp hanging from the unusually high ceiling of the elevator. You design a lamp which has three sections which hang one directly below the other. Each section is attached to the previous one by a single thin wire which also carries the electric current. The lamp is also attached to the ceiling by a single wire. Each section of the lamp weighs 7.0 N. Because the idea is to make each section appear that it is floating on air without support, you want to use the thinnest wire possible. Unfortunately the thinner the wire, the weaker it is. To determine the thinnest wire that can be used for each stage of the lamp, calculate the force on each wire in case of an emergency stop.

4. You are investigating an elevator accident which happened in a tall building. An elevator in this building is attached to a strong cable which runs over a pulley attached to a steel support in the roof. The other end of the cable is attached to a block of metal called a counterweight which hangs freely. An electric motor on the side of the elevator drives the elevator up or down by exerting a force on the side of the elevator shaft. You suspect that when the elevator was fully loaded, there was too large a force on the

motor . A fully loaded elevator at maximum capacity weighs 2400 lbs. The counterweight weighs 1000 lbs. The elevator always starts from rest at its maximum acceleration of g/4 whether it is going up or down.

(a) What force does the wall of the elevator shaft exert on the motor if the elevator starts from rest and goes up?

(b) What force does the wall of the elevator shaft exert on the motor if the elevator starts from rest and goes down?

5. **Tension, Weight:** An artist friend of yours wants your opinion of his idea for a new kinetic sculpture. The basic concept is to balance a heavy object with two lighter objects using two very light pulleys, which are essentially frictionless, and lots of string. The sculpture has one pulley hanging from the ceiling by a string attached to its center. Another string passes over this pulley. One end of this string is attached to a 25-lb object while the other supports another pulley at its center. This second pulley also has a string passing over it with one end attached to a 10-lb object and the other to a 15-lb object. Your friend hasn't quite figured out the rest of the sculpture but wants to know if, ignoring the mass of the pulley and string, the 25-lb object will remain stationary during the time that the 10-lb and 15-lb objects are accelerating.
DO ONLY THE PROBLEM SOLVING STEPS NECESSARY TO FOCUS THE PROBLEM, DESCRIBE THE PHYSICS OF THE PROBLEM, AND PLAN A SOLUTION. DO NOT SOLVE THIS PROBLEM.

6. **Weight, Normal, Friction:** Because of your physics background, you have been able to get a job with a company devising stunts for an upcoming adventure movie being shot in Minnesota. In the script, the hero has been fighting the villain on the top of the locomotive of a train going down a straight horizontal track at 20 mph. He has just snuck on the train as it passed over a lake so he is wearing his rubber wet suit. During the fight, the hero slips and hangs by his fingers on the top edge of the front of the locomotive. The locomotive has a smooth steel vertical front face. Now the villain stomps on the hero's fingers so he will be forced to let go and slip down the front of the locomotive and be crushed under its wheels. Meanwhile, the hero's partner is at the controls of the locomotive trying to stop the train. To add to the suspense, the brakes have been locked by the villain. It will take her 10 seconds to open the lock. To her horror, she sees the hero's fingers give way before she can get the lock off. Since she is the brains of the outfit, she immediately opens the throttle causing the train to accelerate forward. This causes the hero to stay on the front face of the locomotive without slipping down giving her time to save the hero's life. The movie company wants to know what minimum acceleration is necessary to perform this stunt. The hero weighs 180 lbs. in his wet suit. The locomotive weighs 100 tons. You look in a book giving the properties of materials and find that the coefficient of kinetic friction for rubber on steel is 0.50 and its coefficient of static friction is 0.60.

7. **Weight, Normal, Friction:** While working in a mechanical structures laboratory, your boss assigns you to test the strength of ropes under different conditions. Your test set-up consists of two ropes attached to a 30 kg block which slides on a 5.0 m long horizontal table top. Two low friction, light weight pulleys are mounted at opposite ends of the table. One rope is attached to each end of the 30 kg block. Each of these ropes runs horizontally over a different pulley. The other end of one of the ropes is attached to a 12 kg block which hangs straight down. The other end of the second rope is attached to a 20 kg block also hanging straight down. The coefficient of kinetic friction between the block on the table and the table's surface is 0.08. The 30 kg block is initially held in place by a mechanism that is released when the test begins so, that the block is accelerating during the test. During this test, what is the force exerted on the rope supporting the 12 kg block?

Linear Acceleration, Force Components

8. **Human, Weight, Normal:** You are taking care of two small children, Sarah and Rachel, who are twins. On a nice cold, clear day you decide to take them ice skating on Lake of the Isles. To travel across the frozen lake you have Sarah hold your hand and Rachel's hand. The three of you form a straight line as you skate, and the two children just glide. Sarah must reach up at an angle of 60 degrees to grasp your hand, but she grabs Rachel's hand horizontally. Since the children are twins, they are the same height and the same weight, 50 lbs. To get started you accelerate at 2.0 m/s^2. You are concerned about the force on the children's arms which might cause shoulder damage. So you calculate the force Sarah exerts on Rachel's arm, and the force you exert on Sarah's other arm. You assume that the frictional forces of the ice surface on the skates are negligible.

9. **Tension, Weight, Normal, and Friction:** You are planning to build a log cabin in northern Minnesota. You will pull the logs up a long, smooth hill to the building site by means of a rope attached to a winch. You need to buy a rope for this purpose, so you need to know how strong the rope must be. Stronger ropes cost more. You know that the logs weigh a maximum of 200 kg. You measure that the hill is at an angle of 30^o with respect to the horizontal, and the coefficient of kinetic friction between a log and the hill is 0.90. When pulling a log up the hill, you will make sure that the rope stays parallel to the surface of the hill and the acceleration of the log is never more than 0.80 m/s^2. How strong a rope should you buy?

10. **Tension, Weight, Normal, Friction:** You have taken a summer job at a warehouse and have designed a method to help get heavy packages up a 15° ramp. In your system a package is attached to a rope which runs parallel to the ramp and over a pulley at the top of the ramp. After passing over the pulley the other end of the rope is attached to a counterweight which hangs straight down. In your design the mass of the counterweight is always adjusted to be twice the mass of the package. Your boss is worried about this pulley system. In particular, she is concerned that the package will be too difficult to handle at the top of the ramp and tells you to calculate its acceleration. To determine the influence of friction between the ramp and the package you run some tests. You find that you can push a 50 kg package with a horizontal force of 250 Newtons at a constant speed along a level floor made of the same material as the ramp.

11. **Tension, Weight, Normal, Friction:** After graduating you get a job in Northern California. To move there, you rent a truck for all of your possessions. You also decide to take your car with you by towing it behind the truck. The instructions you get with the truck tells you that the maximum truck weight when fully loaded is 20,000 lbs. and that the towing hitch that you rented has a maximum strength of 1000 lbs. Just before you leave, you weigh the fully loaded truck and find it to be 15,000 lbs. At the same time you weigh your car and find it to weigh 3000 lbs. You begin to worry if the hitch is strong enough. Then you remember that you can push your car and can easily keep it moving at a constant velocity. You know that air resistance will increase as the car goes faster but from your experience you estimate that the sum of the forces due to air resistance and friction on the car is not more than 300 lbs. If the largest hill you have to go up is sloped at 10^o from the horizontal, what is the maximum acceleration you can safely have on that hill?
DO ONLY THE PROBLEM SOLVING STEPS NECESSARY TO FOCUS THE PROBLEM, DESCRIBE THE PHYSICS OF THE PROBLEM, AND PLAN A SOLUTION. DO NOT SOLVE THIS PROBLEM.

12. **Weight, Normal, Friction:** Because of your physics background, you have been able to get a job with a company devising stunts for an upcoming adventure movie being shot in Minnesota. In the script, the hero has been fighting the villain on the top of the locomotive of a train going down a straight horizontal track at 20 mph. He has just snuck on the train as it passed over a lake so he is wearing his rubber wet suit. During the fight, the hero slips and hangs by his fingers on the top edge of the front of the locomotive. The locomotive has a smooth steel front face sloped at 20^o from the vertical so that the bottom of the front is more forward that the top. Now the villain stomps on the hero's fingers so he will be forced to let go and slip down the front of the locomotive and be crushed under its wheels. Meanwhile, the hero's partner is at the controls of the locomotive trying to stop the train. To add to the suspense, the brakes have been locked by the villain. It will take her 10 seconds to open the lock. To her horror, she sees the hero's fingers give way before she can get the lock off. Since she is the brains of the outfit, she immediately opens the throttle causing the train to accelerate forward. This causes the hero to stay on the front face of the locomotive without slipping down giving her time to save the hero's life. The movie company wants to know what minimum acceleration is necessary to perform this stunt. The hero weighs 180 lbs. in his wet suit. The locomotive weighs 100 tons. You look in a book giving the properties of materials and find that the coefficient of kinetic friction for rubber on steel is 0.50 and its coefficient of static friction is 0.60.

13. **Gravitational:** You have been hired as a consultant for the new Star Trek TV series to make sure that any science on the show is correct. In this episode, the crew of the Enterprise discovers an abandoned space station in deep space far from any stars. This station is obviously the work of an advanced race and consists of four identical 3×10^{20} kg asteroids configured so that each is at the corner of a square with 200 km sides. According to the tricorder, the station has been abandoned for at least two centuries. You know that such a configuration is unstable and worry whether there would be observable motion of the asteroids after two hundred years so you calculate the acceleration of one of the asteroids in the proposed configuration. Make sure you give both the magnitude and the direction of the acceleration.

14. **Gravitational:** Because the movie industry is trying to make the technical details of movies as correct as possible, you have been made a member of a panel reviewing the details of a new science fiction script. Although neither astronomy nor navigation is your field, you are disturbed by one scene in which a space ship which is low on fuel is attempting to land on the Earth. As the ship approaches, it is heading straight for the center of the Earth. The commander cuts off the ship's engines so that it will be pulled in by the Earth's gravitational force. As the commander looks in the viewer, she sees the Earth straight ahead and the Moon off to the left at an angle of 30^o. The line between the centers of the Moon and Earth is at right angles to the initial path of the space ship. Under these conditions you don't think the ship will continue heading toward the Earth, so you calculate the component of its acceleration which is perpendicular to the initial path of the ship. First you look up the distance between the Earth and the Moon (3.8×10^5 km), the mass of the Earth (6.0×10^{24} kg), the mass of the Moon (7.3×10^{22} kg), the radius of the Earth (6.4×10^3 km), the radius of the Moon (1.7×10^3 km), and the universal gravitational constant (6.7×10^{-11} N m^2/kg^2). As a first approximation, you decide to neglect the effect of the Sun and the other planets in the solar system. You guess that a space ship such as described in the script might have a mass of about 100,000 kg.

No Acceleration (a = 0), No Force Components

15. **Weight - Buoyancy, Normal, Friction, Electric:** The quarter is almost over so you decide to have a party. To add atmosphere to your otherwise drab apartment, you decide to decorate with balloons. You buy about fifty and blow them up so that they are all sitting on your carpet. After putting most of them up, you decide to play with the few balloons left on the floor. You rub one on your sweater and find that it will "stick" to a wall. Ah ha, you know immediately that you are observing the electric force in action. Since it will be some time before you guests arrive and you have already made the onion dip, you decide to calculate the minimum electric force of the wall on the balloon. You know that the air exerts a net upward force (the "buoyant" force) on the balloon which makes it almost float. You measure that the weight of the balloon minus the buoyant force of the air on the balloon is 0.05 lb. By reading your physics book, you estimate that the coefficient of static friction between the wall and the balloon (rubber and concrete) is 0.80.

16. **Tension, Weight, Electric:** While working in a University research laboratory you are given the job of testing a new device for precisely measuring the weight of small objects. The device consists of two very light strings attached at one end to a support. An object is attached to the other end of each string. The strings are far enough apart so that objects hanging on them don't touch. One of the objects has a very accurately known weight while the other object is the unknown. A power supply is slowly turned on to give each object an electric charge which causes the objects to slowly move away from each other (repel) because of the electric force. When the power supply is kept at its operating value, the objects come to rest at the same horizontal level. At that point, each of the strings supporting them makes a different angle with the vertical and that angle is measured. To test the device, you want to calculate the weight of an unknown sphere from the measured angles and the weight of a known sphere. You use a standard sphere with a known weight of 2.000 N supported by a string which makes an angle of 10.0° with the vertical. The unknown sphere's string makes an angle of 20.0° with the vertical.

17. **Gravitational:** You are writing a short science fiction story for your English class. You get your idea from the fact that when people cross the Earth's equator for the first time, they are awarded a certificate to commemorate the experience. In your story it is the 21st Century and you are the tour director for a trip to the moon. Transplanetary Tours promises tour participants a certificate to commemorate their passage from the stronger influence of the Earth's gravitational pull to the stronger gravitational pull of the moon. To finish the story, you need to figure out where on the trip you should award the certificate. In your physics book you look up the distance between the Earth and the Moon (3.8×10^5 km), the mass of the Earth (6.0×10^{24} kg), the mass of the Moon (7.3×10^{22} kg), the radius of the Earth

    (6.4×10^3 km), the radius of the Moon (1.7×10^3 km), and the universal gravitational constant (6.7×10^{-11} N m^2/kg^2).

18. **Gravitational:** You have been hired as a consultant for the new Star Trek TV series to make sure that the science in the show is correct. In this episode, the crew of the Enterprise goes into standard orbit around a newly discovered planet. The plot requires that the planet is hollow and contains the underground cities of a lost civilization. From orbit the science officer determines that the radius of the planer is 1/4 (one-fourth) that of Earth. The first officer beams down to the surface of the planet and measures that his weight is only 1/2 (one-half) of his weight on Earth. How does the mass of this

planet compare with the mass of the Earth? If it were hollow, its density would be less than Earth. Are the measurements consistent with a hollow planet?

19. **Gravitational, Electric:** You and a friend are reading a newspaper article about nuclear fusion energy generation in stars. The article describes the helium nucleus, made up of two protons and two neutrons, as very stable so it doesn't decay. You immediately realize that you don't understand why the helium nucleus is stable. You know that the proton has the same charge as the electron except that the proton charge is positive. Neutrons you know are neutral. Why, you ask your friend, don't the protons simply repel each other causing the helium nucleus to fly apart? Your friend says she knows why the helium nucleus does not just fly apart. The gravitational force keeps it together, she says. Her model is that the two neutrons sit in the center of the nucleus and gravitationally attract the two protons. Since the protons have the same charge, they are always as far apart as possible on opposite sides of the neutrons. What mass would the neutron have if this model of the helium nucleus works? Is that a reasonable mass? Looking in your physics book, you find that the mass of a neutron is about the same as the mass of a proton and that the diameter of a helium nucleus is 3.0×10^{-13} cm.

No Acceleration (a = 0), Force Components

20. **Tension, Weight, Friction:** You are taking advantage of an early snow to go sledding. After a long afternoon of going up and down hills with your sled, you decide it is time to go home. You are thankful that you can pull your sled without climbing any more hills. As you are walking home, dragging the sled behind you by a rope fastened to the front of the sled, you wonder what the coefficient of friction of the snow on the sled is. You estimate that you are pulling on the rope with a 2 pound force, that the sled weighs 10 pounds, and that the rope makes an angle of 25 degrees to the level ground.

21. **Human, Weight, Normal, Friction:** You are helping a friend move into a new apartment. A box weighing 150 lbs. needs to be moved to make room for a couch.. You are taller than the box, so you reach down to push it at an angle of 50 degrees from the horizontal. The coefficient of static friction between the box and the floor is 0.50 and the coefficient of kinetic friction between the box and the floor is 0.30.
    (a) If you want to exert the minimum force necessary, how hard would you push to keep the box moving across the floor?
    (b) Suppose you bent your knees so that your push were horizontal. How hard would you push to keep the box moving across the floor?

22. **Human, Weight, Normal, Friction:** You are helping an investigation of back injuries in the construction industry. Your assignment is to determine why there is a correlation of the height of the worker to the likelihood of back injury. You suspect that some back injuries are related to the way people push heavy objects in order to move them. When people push an object, such as a box, across the floor they tend to lean down and push at an angle to the horizontal. Taller people push at a larger angle with respect to the horizontal than shorter people. To present your ideas to the rest of the research team, you decide to calculate the force a 200-lb box exerts on a 150-lb person when they push it across a typical floor at a constant velocity of 7.0 ft/s as a function of the angle with respect to the horizontal at which the person pushes the box. Once you have your function, you will use angles of 0^o, 10^o, 20^o, 30^o, and 40^o to make a graph of the result for the presentation. One of your coworkers tells you that a typical coefficient of static friction between a box and a floor of 0.60 and while a typical coefficient of kinetic friction between a box and a floor is 0.50. (Don't forget to make the graph).

23. **Tension, Weight:** Your are part of a team to help design the atrium of a new building. Your boss, the manager of the project, wants to suspend a 20-lb sculpture high over the room by hanging it from the ceiling using thin, clear fishing line (string) so that it will be difficult to see how the sculpture is held up. The only place to fasten the fishing line is to a wooden beam which runs around the edge of the room at the ceiling. The fishing line that she wants to use will hold 20 lbs. (20-lb test) so she suggests attaching two lines to the sculpture to be safe. Each line would come from the opposite side of the ceiling to attach to the hanging sculpture. Her initial design has one line making an angle of 20^o with the ceiling and the other line making an angle of 40^o with the ceiling. She knows you took physics, so she asks you if her design can work.

24. **Electric, Weight, Tension:** While working in a University research laboratory you are given the job of testing a new device, called an electrostatic scale, for precisely measuring the weight of small objects. The device is quite simple. It consists of two very light but strong strings attached to a support so that they hang straight down. An object is attached to the other end of each string. One of the objects has a very accurately known weight while the other object is the unknown. A power supply is slowly turned on to give each object an electric charge which causes the objects to slowly move away from each other (repel) because of the electric force. When the power supply is kept at its operating value, the objects come to rest at the same horizontal level. At that point, each of the strings supporting them makes a different angle with the vertical and that angle is measured. To test the device, you want to calculate the weight of an unknown sphere from the measured angles and the weight of a known sphere. You use a standard sphere with a known weight of 2.00000 N supported by a string which makes an angle of 10.00^o with the vertical. The unknown sphere's string makes an angle of 20.00^o with the vertical.

Force and Linear Kinematics

The following problems require both Newton's Laws of Motion and one or more kinematics relationship for a solution. The specific types of forces involved in a problem (e.g., human push or pull, tension, normal, weight, friction, gravitational, electric) are indicated in bold type at the beginning of each problem.

25. **Weight, Normal:** While driving in the mountains, you notice that when the freeway goes steeply down hill, there are emergency exits every few miles. These emergency exits are straight dirt ramps which leave the freeway and are sloped uphill. They are designed to stop trucks and cars that lose their breaks on the downhill stretches of the freeway even if the road is covered in ice. You are curious, so you stop at the next emergency road. You estimate that the road rises at an angle of 10^o from the horizontal and is about 100 yards (300 ft) long. What is the maximum speed of a truck that you are sure will be stopped by this road, even if the frictional force of the road surface is negligible?

26. **Weight, Normal:** While driving in the mountains, you notice that when the freeway goes steeply down hill, there are emergency exits every few miles. These emergency exits are straight dirt ramps which leave the freeway and are sloped uphill. They are designed to stop trucks and cars that lose their breaks on the downhill stretches of the freeway even if the road is covered in ice. You wonder at what angle from the horizontal an emergency exit should rise to stop a 50 ton truck going 70 mph up a ramp 100 yards (300 ft) long, even if the frictional force of the road surface is negligible.

27. **Weight, Normal:** You and a few friends have decided to open a small business called Wee Deliver. The business will guarantee to deliver any box between 5 lbs. and 500 lbs. to any location in the Twin City area by the next day. At your distribution center, boxes slide down a ramp between the delivery area and the sorting area. In designing the distribution center, you must determine the angle this ramp should have with the horizontal so that a 500-lb box takes 5.0 seconds to slide down the ramp starting from rest at the top. When the box arrives at the bottom of the ramp, its speed should not be too large or the contents of the box might be damaged. You decide that this speed should be 10 ft/s. Using the latest technology, your ramp will have a very slippery surface so you make the approximation that the frictional force between the ramp and the box can be neglected.

28. **Weight, Normal:** You are watching a ski jump contest on television when you wonder how high the skier is when she leaves the starting gate. In the ski jump, the skier glides down a long ramp. At the end of the ramp, the skier glides along a short horizontal section which ends abruptly so that the skier goes into the air. You measured that the skier was in the air for 2.3 seconds and landed 87 meters, in the horizontal direction, from the point she went into the air. Make the best estimate of the height of the starting gate at the top of the ramp from the horizontal section from which the skier takes off into the air. Make clear on what assumptions your answer depends (this is why it is an estimate).

29. **Weight, Normal, Friction:** You are passing a construction site on the way to physics class, and stop to watch for awhile. The construction workers appear to be going on coffee break, and have left a large concrete block resting at the top of a wooden ramp. As soon as their backs are turned, the block begins to slide down the ramp. You quickly clock the time for the block to reach the bottom of the ramp at 10 seconds. You wonder how long the ramp is. You estimate that the ramp is at an angle of about 20^o to the horizontal. In your physics book you find that the coefficient of kinetic friction between concrete and wood is 0.35.

30. **Weight, Normal, Friction:** You have a summer job at a company that specializes in the design of sports facilities. The company has been given the contract to design a new hockey rink to try to keep the North Stars in town. The rink floor is very flat and horizontal and covered with a thick coat of ice. Your task is to determine the refrigeration requirements which gives best temperature for the ice. You have a table which gives the coefficient of static and kinetic friction between ice and the standard NHL hockey puck as a function of ice temperature. You have been told that the hockey game will be more exciting if passes are swift and sure. Experts say that the passing game is best if, after it goes 5.0 m, a puck has a speed which is 90% of the speed with which it left the hockey stick. A puck typically has a speed of 20 km/hr when it leaves the hockey stick for a pass.

31. **Weight, Normal, Friction:** You and some friends visit the Minnesota State Fair and decide to play a game on the Midway. To play the game you must slide a metal hockey-type puck up a wooden ramp so that it drops through a hole at the top of the ramp. Your prize, if you win, is a large, pink, and rather gaudy, stuffed poodle. You realize the secret to winning is giving the puck just enough velocity at the bottom of the ramp to make it to the hole. You estimate the distance from the bottom of the ramp to the hole at about 10 feet, and the ramp appears to be inclined with an angle of 10^{o} from the horizontal. You just got out of physics class and recall the coefficient of static friction between steel and wood is 0.1 and the coefficient of kinetic friction between steel and wood is 0.08. The mass of the puck is about 2.5 lbs. You decide to impress your friends by sliding the puck at the precise speed on the first try so as to land it in the hole. You slide the puck at 8.0 ft/sec. Do you win the stuffed poodle?

32. **Weight, Normal, Tension, Friction:** Finally you are leaving Minneapolis to get a few days of Spring break, but your car breaks down in the middle of nowhere. A tow truck weighing 4000 lbs. comes along and agrees to tow your car, which weighs 2000 lbs., to the nearest town. The driver of the truck attaches his cable to your car at an angle of 20^{o} to the horizontal. He tells you that his cable has a strength of 500 lbs. He plans to take 10 seconds to tow your car at a constant acceleration from rest in a straight line along the flat road until he reaches the maximum speed limit of 45 miles/hour. Can the driver carry out his plan? You assume that rolling friction behaves like kinetic friction, and the coefficient of rolling friction between your tires and the road is 0.10.

33. **Weight, Normal, Friction:** While visiting a friend in San Francisco you decide to drive around the city. You turn a corner and are driving up a steep hill. Suddenly, a small boy runs out on the street chasing a ball. You slam on the brakes and skid to a stop leaving a 50 foot long skid mark on the street. The boy calmly walks away but a policeman watching from the sidewalk walks over and gives you a ticket for speeding. You are still shaking from the experience when he points out that the speed limit on this street is 25 mph. After you recover your wits, you examine the situation more closely. You determine that the street makes an angle of 20^{o} with the horizontal and that the coefficient of static friction between your tires and the street is 0.80. You also find that the coefficient of kinetic friction between your tires and the street is 0.60. Your car's information book tells you that the mass of your car is 1570 kg. You weigh 130 lbs. Witnesses say that the boy had a weight of about 60 lbs. and took 3.0 seconds to cross the 15 foot wide street. Will you fight the ticket in court?

34. **Weight, Lift, Thrust, Drag:** One morning while waiting for class to begin, you are reading a newspaper article about airplane safety. This article emphasizes the role of metal fatigue in recent accidents. Metal fatigue results from the flexing of airframe parts in response to the forces on the plane especially during take off and landings. As an example, the reporter uses a plane with a take off weight of 200,000 lbs. and take off speed of 200 mph which climbs at an angle of 30^{o} with a constant

acceleration to reach its cruising altitude of 30,000 feet with a speed of 500 mph. The three jet engines provide a forward thrust of 240,000 lbs. by pushing air backwards. The article then goes on to explain that a plane can fly because the air exerts an upward force on the wings perpendicular to their surface called "lift." You know that air resistance is also a very important force on a plane and is in the direction opposite to the velocity of the plane. The article tells you this force is called the "drag." Although the reporter writes that some metal fatigue is primarily caused by the lift and some by the drag, she never tells you their size for her example plane. Luckily the article contains enough information to calculate them, so you do.

Force and Circular Motion at a Constant Speed

The problems in this section require the application of Newton's Laws of Motion as well as the relationships between speed, frequency, and radial acceleration for circular motion at a constant speed. The problems are divided into two groups: (1) No radial force components required for solution; and (2) Radial force components required for solution. The specific types of forces involved in a problem (e.g., tension, normal, weight, friction, gravitational, electric) are indicated in bold type at the beginning of each problem.

No Radial Force Components

35. **Weight, Normal:** Just before finals you decide to visit an amusement park set up in the Metrodome. Since it is a weekend, you invite your favorite niece along. She loves to ride on a Ferris wheel, and there is one at the amusement park. The Ferris wheel has seats on the rim of a circle with a radius of 25 m. The Ferris wheel rotates at a constant speed and makes one complete revolution every 20 seconds. While you wait, your niece who has a mass of 42 kg, rides the Ferris wheel. To kill time you decide to calculate the total force (both magnitude and direction) on her when she is one quarter revolution past the highest point. Because the Ferris wheel can be run at different speeds, you also decide to make a graph which gives the magnitude of the force on her at that point as a function of the period of the Ferris wheel.

36 **Weight, Normal:** While relaxing from studying physics, you watch some TV. While flipping through channels you see a circus show in which a woman drives a motorcycle around the inside of a vertical ring. You determine that she goes around at a constant speed and that it takes her 4.0 seconds to get around when she is going her slowest. If she is going at the minimum speed for this stunt to work, the motorcycle is just barely touching the ring when she is upside down at the top. At that point she is in free fall so her acceleration is just g. She just makes it around without falling off the ring but what if she made a mistake and her motorcycle fell off at the top? How high up is she?

37. **Weight, Normal, Friction:** The producer of the last film you worked on was so impressed with the way you handled a helicopter scene that she hired you again as technical advisor for a new "James Bond" film. The scene calls for 007 to chase a villain onto a merry-go-round. An accomplice starts the merry-go-round rotating in an effort to toss 007 (played in this new version by Billy Crystal) off into an adjacent pool filled with hungry sharks. You must determine a safe rate of rotation such that the stunt man (you didn't think Billy would do his own stunts did you?) will *not* fly off the merry-go-round and into the shark-infested pool. (Actually they are mechanical sharks, but the audience doesn't know that.) You measure the diameter of the merry-go-round as 50 meters. You determine that the coefficient of static friction between 007's shoes and the merry-go-round surface is 0.7 and the coefficient of kinetic friction is 0.5.

38. **Weight, Normal, Friction:** A new package moving system in the new, improved post office consists of a large circular disc (i.e. a turntable) which rotates once every 3.0 seconds at a constant speed in the horizontal plane. Packages are put on the outer edge of the turntable on one side of the room and taken off on the opposite side. The coefficient of static friction between the disc surface and a package is 0.80 while the coefficient of kinetic friction is 0.60. If this system is to work, what is the maximum possible radius of the turntable?

39. **Weight, Normal, Friction:** You are driving with a friend who is sitting to your right on the passenger side of the front seat. You would like to be closer to your friend and decide to use your knowledge of physics to achieve your romantic goal. So you'll make a sharp turn. Which direction should you turn so as to make your friend slide closer to you? If the coefficient of static friction between your friend and the seat of the car is 0.40, and you drive at a constant speed of 18 m/s, what is the maximum radius you could make your turn and still have your friend slide your way?

40. **Weight, Normal, Friction:** On a trip through Florida, you find yourself driving in your 3000-lb car along a flat level road at 50 mph. The road makes a turn which you take without changing your speed. The curve is approximately an arc of a circle with a radius of 0.05 miles. You notice that the curve is flat and level with no sign of banking. There are no warning signs but you wonder if it would be safe to try to go 50 mph around the curve in the rain when the wet surface has a lower coefficient of friction. What is the minimum coefficient of static friction between the road and your car's tires which will allow your car to make the turn?

41. **Weight, Tension:** After watching the movie "Crocodile Dundee," you and some friends decide to make a communications device invented by the Australian Aborigines. It consists of a noise-maker swung in a vertical circle on the end of a string. Your design calls for a 400 gram noise-maker on a 60 cm string. You are worried about whether the string you have will be strong enough, so you decide to calculate the tension in the string when the device is swung with an acceleration which has a constant magnitude of 20 m/s^2 . You and your friends can't agree whether the maximum tension will occur when the noise maker is at the highest point in the circle, at the lowest point in the circle, or is always the same. To settle the argument you decide to calculate the tension at the highest point and at the lowest point and compare them.

42. You are watching a TV news program when they switch to some scenes taken aboard the space shuttle which circles 500 miles above the Earth once every 95 minutes. To allow the audience to appreciate the distances involved, the announcer tells you that the radius of the Earth is about 4000 miles and the distance from the Earth to the Moon is about 250,000 miles. When an astronaut drops her pen it floats in front of her face. You immediately wonder how the acceleration of the dropped pen compares to the acceleration of a pen that you might drop here on the surface of the Earth.

43. **Gravitational:** You are still a consultant for the new Star Trek TV series. You were hired to make sure that any science on the show is correct. In this episode, the crew of the Enterprise discovers an abandoned space station in deep space far from any stars. This station, which was built by Earth in the 21st century, is a large wheel-like structure where people live and work in the rim. In order to create "artificial gravity," the space station rotates on its axis. The special effects department wants to know at what rate a space station 200 meters in diameter would have to rotate to create "gravity" equal to 0.7 that of Earth.

44. **Gravitational:** You did so well in your physics course that you decided to try to get a summer job working in a physics laboratory at the University. You got the job as a student lab assistant in a research group investigating the ozone depletion at the Earth's poles. This group is planning to put an atmospheric measuring device in a satellite which will pass over both poles. To collect samples of the upper atmosphere, the satellite will be in a circular orbit 200 miles above the surface of the Earth. To adjust the instruments for the proper data taking rate, you need to calculate how many times per day the device will sample the atmosphere over the South pole. Using the inside cover of your trusty

Physics text you find that the radius of the Earth is 6.38×10^3 km, the mass of the Earth is 5.98×10^{24} kg, and the universal gravitational constant is 6.7×10^{-11} N m^2/kg^2.

45. **Gravitational:** You did so well in your physics course that you decided to try to get a summer job working in a physics laboratory at the University. You got the job as a student lab assistant in a research group investigating the ozone depletion at the Earth's poles. This group is planning to put an atmospheric measuring device in a satellite which will pass over both poles. To collect samples of the upper atmosphere, the satellite will be in a circular orbit 200 miles above the surface of the Earth where g is 95% of its value on the Earth's surface. To adjust the instruments for the proper data taking rate, you need to calculate how many times per day the device will sample the atmosphere over the South pole. Using the inside cover of your trusty Physics text you find that the radius of the Earth is 6.38×10^3 km and the mass of the Earth is 5.98×10^{24} kg.

46. **Gravitational:** You are reading a magazine article about pulsars. A few years ago, a satellite in orbit around the Earth detected X-rays coming from sources in outer space. The X-rays detected from one source, called Cygnus X-3, had an intensity which changed with a period of 4.8 hours. This type of astronomical object emitting periodic signals is called a pulsar. One popular theory holds that the pulsar is a normal star (similar to our Sun) which is in orbit around a much more massive neutron star. The period of the X-ray signal is then the period of the orbit. In this theory, the distance between the normal star and the neutron star is approximately the same as the distance between the Earth and our Sun. You realize that if this theory is correct, you can determine how much more massive the neutron star is than our Sun. All you need to do is first find the mass of the neutron star in terms of two unknowns, the universal gravitational constant G and the radius of the Earth's orbit. Then find the mass of our Sun in terms of the same two unknowns, G and the radius of the Earth's orbit. (The period of the Earth's orbit is 1 year). Then you can calculate how many times more massive the neutron star is than our Sun.

Radial Force Components

47. **Weight, Lift:** You are reading an article about the aesthetics of airplane design. One example in the article is a beautiful new design for commercial airliners. You are worried that this light wing structure might not be strong enough to be safe. The article explains that an airplane can fly because the air exerts a force, called "lift," on the wings such that the lift is always perpendicular to the wing surface. For level flying, the wings are horizontal. To turn , the pilot "banks" the plane so that the wings are oriented at an angle to the horizontal. This causes the plane to have a trajectory which is a horizontal circle. The specifications of the 100×10^3 lb plane require that it be able to turn with a radius of 2.0 miles at a constant speed of 500 miles/hr. The article states that tests show that the new wing structure will support a force 4 times the lift necessary for level flight. Is the wing structure sufficiently strong for the plane to make this turn?

48. **Weight, Lift:** You are flying to Chicago when the pilot tells you that the plane can not land immediately because of airport delays and will have to circle the airport. This is standard operating procedure. She also tells you that the plane will maintain a speed of 400 mph at an altitude of 20,000 feet while traveling in a horizontal circle around the airport. To pass the time you decide to figure out how far you are from the airport. You notice that to circle, the pilot "banks" the plane so that the wings are oriented at 10^o to the horizontal. An article in your in-flight magazine explains that an airplane can fly because the air exerts a force, called "lift," on the wings. The lift is always perpendicular to the wing

surface. The magazine article gives the weight of the type of plane you are on as 100×10^3 pounds and the length of each wing as 150 feet. It gives no information on the thrust of the engines or the drag of the airframe.

49. Because of your physics background, you have been hired as a member of the team the state highway department has assigned to review the safety of Minnesota freeways. This week you are studying 35W which has a curve which is essentially 1/8 of a circle with a radius of 0.5 miles. The road has been designed with a banked curve so that the road makes an angle of 4° to the horizontal throughout the curve. To begin the study, the head of your department asks that you calculate the maximum speed for a standard passenger car (about 2000 lbs.) to complete the turn while maintaining a horizontal path along the road. She asks that you first consider the case of a slick, ice covered road. When you have completed that calculation she wants you to do the case of a dry, clear road where the coefficient of kinetic friction is 0.70 and the coefficient of static friction is 0.80 between the tires and the road. This will give her team the two extremes of Minnesota driving conditions on which to base the analysis.

50. **Tension, Weight:** A neighbor's child wants to go to a neighborhood carnival to experience the wild rides. The neighbor is worried about safety because one of the rides looks dangerous. She knows that you have taken physics and so asks your advice. The ride in question has a 10-lb chair which hangs freely from a 30-ft long chain attached to a pivot on the top of a tall tower. When a child enters the ride, the chain is hanging straight down. The child is then attached to the chair with a seat belt and shoulder harness. When the ride starts up the chain rotates about the tower. Soon the chain reaches its maximum speed and remains rotating at that speed. It rotates about the tower once every 3.0 seconds. When you ask the operator, he says that the ride is perfectly safe. He demonstrates this by sitting in the stationary chair. The chain creaks but holds and he weighs 200 lbs. Has the operator shown that this ride safe for a 50-lb child?

Conservation of Energy
Conservation of Momentum

The problems in this section require conservation principles to solve -- the conservation of energy, the conservation of momentum, or both. For convenience, the problems are divided into four groups by the concepts required for a solution: (1) conservation of energy (mechanical, gravitational); (2) conservation of energy (mechanical) and force; (3) conservation of momentum; and (4) conservation of energy (mechanical) and conservation of momentum.

Conservation of Energy (Mechanical, Gravitational)

1. You are watching a National Geographic Special on television. One segment of the program is about archer fish, which inhabit streams in southeast Asia. This fish actually "shoots" water at insects to knock them into the water so it can eat them. The commentator states that the archer fish keeps its mouth at the surface of the stream and squirts a jet of water from its mouth at 13 feet/second. You watch an archer fish shoot a juicy moth off a leaf into the water. You estimate that the leaf was about 2.5 feet above a stream. You wonder at what minimum angle from the horizontal the water can be ejected from the fish's mouth to hit the moth. Since you have time during the commercial, you quickly calculate this angle.

2. Your artist friend is designing a kinetic sculpture and asks for your help since she knows that you have had physics. Part of her sculpture consists of a 6.0-kg object (you can't tell what it is supposed to be, but it's art) and a 4.0-kg object which hang straight down from opposite ends of a very thin, flexible wire. This wire passes over a smooth, cylindrical, horizontal, stainless steel pipe 3.0 meters above the floor. The frictional force between the rod and the wire is negligible. The 6.0-kg object is held 2.0 meters above the floor and the other object hangs 0.50 meters above the floor. When the mechanism releases the 6.0-kg object, both objects accelerate and one will eventually hit the floor -- but they don't hit each other. To determine if the floor will be damaged, calculate the speed of the object which hits the floor.

3. You are driving your car uphill along a straight road. Suddenly, you see a car run a red light and enter the intersection just ahead of you. You slam on your brakes and skid in a straight line to a stop, leaving skid marks 100 feet long. A policeman observes the whole incident and gives a ticket to the other car for running a red light. He also gives you a ticket for exceeding the speed limit of 30 mph. When you get home, you read your physics book and estimate that the coefficient of kinetic friction between your tires and the road was 0.60, and the coefficient of static friction was 0.80. You estimate that the hill made an angle of about $10^{o}$with the horizontal. You look in your owner's manual and find that your car weighs 2,050 lbs. Will you fight the traffic ticket in court?

4. You have landed a summer job with a company that has been given the contract to design the ski jump for the next Winter Olympics. The track is coated with snow and has an angle of 25^{o} from the horizontal. A skier zips down the ski jump ramp so that he leaves it at high speed. The winner is the person who jumps the farthest after leaving the end of the ramp. Your task is to determine the height of the starting gate above the end of the ramp, which will determine the mechanical structure of the ski jump facility. You have been told that the typical ski-jumper pushes off from the starting gate at a speed of 2.0 m/s. For safety reasons, your design should be such that for a perfect run down the ramp, the

skier's speed before leaving the end of the ramp and sailing through the air should be no more than 80 km/hr. You run some experiments on various skies used by the jumpers and determine that the coefficient of static friction between the snow and the skis is 0.10 and its coefficient of kinetic friction is 0.02. Since the ski-jumpers bend over and wear very aerodynamic suits, you decide to neglect the air resistance to make your design.

5. The Navy wants a new airplane launcher for their aircraft carriers and you are on the design team. The launcher is effectively a large spring that pushes the plane for the first 5 meters of the 20 meter long runway. During that same time, the plane's jet engines supply a constant thrust of 5.4×10^4 N for the entire length of the runway. The 2000 kg planes need to have a velocity of 45 m/s by the end of the runway. What should be the spring constant for the launcher?

6. You have been hired to design a safety system to protect drivers going down hills during an ice storm. The planned system consists of a bumper, which can be considered a stiff spring, at the bottom of the hill. In the scenario you are given, the car starts from rest at the top of a hill which makes an angle θ with the horizontal. The distance that the car slides from the top of the hill until it is stopped by the spring is L. For the worst case scenario, assume that there is no frictional force between the car and road due to the ice. If the maximum compression of the spring from its equilibrium position is D, your job is to calculate the required spring constant k in terms of D, L and θ.

7. You are the technical advisor to the Dave Letterman Show. Your task is to design a circus stunt in which Super Dave Osbourne, who weighs 170 pounds, is shot out of a cannon that is elevated 40^o from the horizontal. The "cannon" is actually a 3-foot diameter tube that uses a stiff spring and a puff of smoke rather than an explosive to launch Super Dave. The manual for the cannon states that the spring constant is 1822 Newtons/meter. The spring is compressed by a motor until its free end is level with the bottom of the cannon tube, which is 5 feet above the ground. A small seat is attached to the free end of the spring for Super Dave to sit on. When the spring is released, it extends 9 feet up the tube. Neither the seat not the chair touch the sides of the 12-foot long tube. After a drum roll, the spring is released and Super Dave will fly through the air with the appropriate sound effects and smoke. You have an airbag 3-feet thick for Super Dave to land on. You know that the airbag will exert an average retarding force of 2850 Newtons in all directions. You need to determine if the airbag is thick enough to stop Super Dave safely. -- that is, so he is slowed to a stop by the time he reaches ground level.

8. Super Dave has just returned from the hospital where he spent a week convalescing from injuries incurred when he was "shot" out of a cannon to land in an airbag which was too thin. Undaunted, he decides to celebrate his return with a new stunt. He intends to jump off a 100-foot tall tower with an elastic cord tied to one ankle, and the other end tied to the top of the tower. This cord is very light but very strong and stretches so that it can stop him without pulling his leg off. Such a cord exerts a force with the same mathematical form as the spring force. He wants it to be 75 feet long so that he will be in free fall for 75 feet before the cord begins to stretch. To minimize the force that the cord exerts on his leg, he wants it to stretch as far as possible. You have been assigned to purchase the cord for the stunt and must determine the elastic force constant which characterizes the cord that you should order. Before the calculation, you carefully measure Dave's height to be 6.0 ft and his weight to be 170 lbs. For maximum dramatic effect, his jump will be off a diving board at the top of the tower. From tests you have made, you determine that his maximum speed coming off the diving board is 10 ft/sec. Neglect air resistance in your calculation -- let Dave worry about that.

9. You were so impressed with the problem about Super Dave that you decide that this would make a good stunt for the Institute of Technology (IT) day. To raise money for a University scholarship fund, you want to have the new IT dean bungee jump from a crane if contributions can be found for 10 scholarships. To add some interest, the jump will be made from 44 m above a 2.5 m deep pool of Jell-O. A 30-m long bungee cord would be attached to the dean's ankle. First you must convince the dean that your plan is safe for a person of his mass, 70 kg. The dean knows that as the bungee cord begins to stretch, it will exert a force which has the same properties as the force exerted by a spring. Your plan has the dean stepping off a platform and being in free fall for the 30 m before the cord begins to stretch. You must determine the elastic constant of the bungee cord so that it stretches only 12 m, which will just keep the dean's head out of the Jell-O.

10. Your friend is an artist. His new work is a kinetic sculpture called "destruction." The sculpture is simple and has high impact. A 200-kg steel block is hung from the ceiling at the end of an 8-foot long rope. Another rope is attached to the block so that it pulls it horizontally. The other end of the horizontal rope is attached to a motor which is cleverly mounted so that the rope always pulls the block horizontally with a constant force. The block starts from rest when it is hanging straight down and moves very slowly until it is hanging at an angle of 30^o to the vertical. At that point the horizontal rope will be released and the block swings until it crashes into a wall. Your friend knows you have taken physics and asks you the minimum energy that the motor must supply. You make a test and determine that the block is in equilibrium when it is pulled by the horizontal rope connected to the motor and the block is hanging from the other rope at 30^o from the vertical.

11. (**Gravitational Energy)** Because of your knowledge of physics and interest in the environment, you have gotten a summer job with an organization which wants to orbit a satellite to monitor the amount of chlorine ions in the upper atmosphere over North America. It has been determined that the satellite should collect samples at a height of 100 miles above the Earth's surface. Unfortunately, at that height air resistance would make the amount of time the satellite would stay in orbit too short to be useful. You suggest that an elliptical orbit would allow the satellite to be close to the Earth over North America, where data was desired, but farther from the Earth, and thus out of almost all of the atmosphere, on the other side of our planet. Your colleague estimates that the satellite would be traveling at 10,000 miles/hour when it was farthest from the Earth at a height of 1,000 miles. How fast would the satellite be traveling when it took its air samples if you neglect air friction?

Conservation of Energy (Mechanical) and Force

12. At the train station, you notice a large horizontal spring at the end of the track where the train comes in. This is a safety device to stop the train so that it will not go plowing through the station if the engineer misjudges the stopping distance. While waiting, you wonder what would be the fastest train that the spring could stop by being fully compressed, 3.0 ft. To keep the passengers as safe as possible when the spring stops the train, you assume that the maximum stopping acceleration of the train, caused by the spring, is g/2. You make a guess that a train might have a mass of 0.5 million kilograms. For the purpose of getting your answer, you assume that all frictional forces are negligible.

13. You have a summer job at a company that specializes in the design of equipment for sports shows and exhibitions. The company has been given the contract to design a piece of apparatus for an ice skating show. An ice skater will start from rest and glide down an ice-covered ramp. At the bottom of the ramp, the skater will continue gliding around in a ice-covered loop which is inside of a vertical circle.

After going around the vertical circle, the skater emerges at the bottom of the circle to glide out on the skating rink floor to the wild applause of the audience. To make a spectacular effect, the circular loop should have a diameter of 30 feet. Your task is to determine the minimum height of the top of the ramp to the rink floor so that the skater will not fall off the loop at the top.

14. In a weak moment you have volunteered to be a human cannonball at an amateur charity circus. The "cannon" is actually a 3-foot diameter tube with a big stiff spring inside which is attached to the bottom of the tube. A small seat is attached to the free end of the spring. The ringmaster, one of your soon to be ex-friends, gives you your instructions. He tells you that just before you enter the mouth of the cannon, a motor will compress the spring to 1/10 its normal length and hold it in that position. You are to gracefully crawl in the tube and sit calmly in the seat without holding on to anything. The cannon will then be raised to an angle such that your speed through the air at your highest point is 10 ft/sec. When the spring is released, neither the spring nor the chair will touch the sides of the 12-foot long tube. After the drum roll, the spring is released and you will fly through the air with the appropriate sound effects and smoke. With the perfect aim of your gun crew, you will fly through the air over a 15-foot wall and land safely in the net. You are just a bit worried and decide to calculate how high above your starting position you will be at your highest point. Before the rehearsal, the cannon is taken apart for maintenance. You see the spring, which is now removed from the cannon, is hanging straight down with one end attached to the ceiling. You determine that it is 10 feet long. When you hang on its free end without touching the ground, it stretches by 2.0 ft. Is it possible for you to make it over the wall?

Conservation of Momentum

15. As a concerned citizen, you have volunteered to serve on a committee investigating injuries to Junior High School students participating in sports programs. Currently your committee is investigating the high incidence of ankle injuries on the basketball team. You are watching the team practice, looking for activities which can result in large horizontal forces on the ankle. Observing the team practice jump shots gives you an idea, so you try a small calculation. A 40-kg student jumps 1.0 meters straight up and shoots the 0.80-kg basketball at his highest point. From the trajectory of the basketball, you deduce that the ball left his hand at 30^{o} from the horizontal at 20 m/s. What is his horizontal velocity when he hits the ground?

16. You are a volunteer at the Campus Museum of Natural History. Because of your interest in the environment and your physics experience, you have been asked to assist in the production of an animated film about the survival of hawks in the wilderness. In the script, a 1.5-kg hawk is hovering in the air so it is stationary with respect to the ground when it sees a goose flying below it. The hawk dives straight down. When it strikes the goose and digs its claws into the goose's body, it has a speed of 60 km/hr. The goose, which has a mass of 2.5 kg, was flying north at 30 km/hr just before it was struck by the hawk and killed instantly. The animators want to know the velocity (magnitude and direction) of the hawk and dead goose just after the strike.

17. You are looking forward to the end of final exams with more anticipation than usual because you have lined up a great summer job. You might be hired by a company searching for treasure in the Caribbean! Your prospective employer has discovered the captain's logbook of the 40,000-ton luxury liner, the Hedonist, which left Miami in 1925 and never returned. In addition to the log, there is a long list of jewelry and other valuables held in the ship's safe. The ship sank when it collided with a freighter and

the wreckage was never found. The log tells that the Hedonist was going due south at a speed of 20 knots in calm seas through a rare fog just before the collision. While in the fog, it was struck broadside by the 60,000-ton freighter, the Ironhorse, which was traveling west at 10 knots. The log tells the exact location (latitude and longitude) of the liner just before the collision. Of course, your employer is keeping that information secret for now. The log also notes that when the freighter's bow pierced the hull of the liner, the two ships were stuck together and sank together. To get the summer job, you are asked to help determine the search area by calculating the velocity (magnitude and direction) of the ships just after collision.

18. You have been hired to check the technical correctness of an upcoming made-for-TV murder mystery. The mystery takes place in the space shuttle. In one scene, an astronaut's safety line is sabotaged while she is on a space walk, so she is no longer connected to the space shuttle. She checks and finds that her thruster pack has also been damaged and no longer works. She is 200 meters from the shuttle and moving with it. That is, she is not moving with respect to the shuttle. There she is drifting in space with only 4 minutes of air remaining. To get back to the shuttle, she decides to unstrap her 10-kg tool kit and throw it away with all her strength, so that it has a speed of 8 m/s. In the script, she survives, but is this correct? Her mass, including space suit, is 80 kg.

Conservation of Energy (Mechanical) and Momentum

19. You have been hired as a technical consultant for an early-morning cartoon series for children to make sure that the science is correct. In the script, a wagon containing two boxes of gold (total mass of 150 kg) has been cut loose from the horses by an outlaw. The wagon starts from rest 50 meters up a hill with a 6^{o} slope. The outlaw plans to have the wagon roll down the hill and across the level ground and then crash into a canyon where his confederates wait. But in a tree 40 meters from the edge of the canyon wait the Lone Ranger (mass 80 kg) and Tonto (mass 70 kg). They drop vertically into the wagon as it passes beneath them. The script states that it takes the Lone Ranger and Tonto 5 seconds to grab the gold and jump out of the wagon, but is this correct?. You assume that the wagon rolls with negligible friction.

20. You are helping your friend prepare for her next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weighs 100 lbs.

21. Because of your physics background, you have been hired as a technical advisor for a new James Bond adventure movie. In the script, Bond and his latest love interest, who is 2/3 his weight (including skis, boots, clothes, and various hidden weapons), are skiing in the Swiss Alps. She skis down a slope while he stays at the top to adjust his boot. When she has skied down a vertical distance of 100 ft, she stops to wait for him and is captured by the bad guys. Bond looks up and sees what is happening. He notices that she is standing with her skis pointed downhill while she rests on her poles. To make as little noise as possible, Bond starts from rest and glides down the slope heading right at her. Just before they collide, she sees him coming and lets go of her poles. He grabs her and they both continue downhill together. At the bottom of the hill, another slope goes uphill and they continue to glide up that slope

until they reach the top of the hill and are safe. The writers want you to calculate the maximum possible height that the second hill can be relative to the position where the collision took place. Both Bond and his girl friend are using new, top-secret frictionless stealth skis developed for the British Secret Service.

22. Because of your concern that incorrect science is being taught to children when they watch cartoons on TV, you have joined a committee which is reviewing a new cartoon version of Tarzan. In this episode, Tarzan is on the ground in front of a herd of stampeding elephants. Just in time Jane, who is up in a tall tree, sees him. She grabs a convenient vine and swings towards Tarzan, who has twice her mass, to save him. Luckily, the lowest point of her swing is just where Tarzan is standing. When she reaches him, he grabs her and the vine. They both continue to swing to safety over the elephants up to a height which looks to be about 1/2 that of Jane's original position. To decide if you going to approve this cartoon, calculate the maximum height Tarzan and Jane can swing as a fraction of her initial height.

23. You are watching a Saturday morning cartoon concerning a jungle hero called George of the Jungle. George attempts to save his friend, an ape named Ape, from a stampeding herd of wildebeests. Ape is at the base of a tall tree which has a vine attached to its top. George is in another tree holding the other end of the vine. George plans to swing down from the tree, grab Ape at the bottom of the swing, and continue up to safety on a ledge which is half of George's initial height in the tree. Assuming that Ape weighs the same as George, will they successfully make it to the top of the ledge?

24. Your friend has just been in a traffic accident and is trying to negotiate with the insurance company of the other driver to pay for fixing her car. She believes that the other car was speeding and therefore the accident was the other driver's fault. She knows that you have a knowledge of physics and hopes that you can prove her conjecture. She takes you out to the scene of the crash and describes what happened. She was traveling North when she entered the fateful intersection. There was no stop sign, so she looked in both directions and did not see another car approaching. It was a bright, sunny, clear day. When she reached the center of the intersection, her car was struck by the other car which was traveling East. The two cars remained joined together after the collision and skidded to a stop. The speed limit on both roads entering the intersection is 50 mph. From the skid marks still visible on the street, you determine that after the collision the cars skidded 56 feet at an angle of 30º north of east before stopping. She has a copy of the police report which gives the make and year of each car. At the library you determine that the weight of her car was 2600 lbs. and that of the other car was 2200 lbs., where you included the driver's weight in each case. The coefficient of kinetic friction for a rubber tire skidding on dry pavement is 0.80. It is not enough to prove that the other driver was speeding to convince the insurance company. She must also show that she was under the speed limit.

25. Because movie producers have come under pressure for teaching children incorrect science, you have been appointed to help a committee of concerned parents review a script for a new Superman movie. In the scene under consideration, Superman rushes to save Lois Lane who has been pushed from a window 300 feet above a crowded street. Superman is 0.5 miles away when he hears Lois scream and rushes to save her. He swoops down in the nick of time, arriving when Lois is just 3.0 feet above the street, and stopping her just at ground level. Lois changes her expression from one of horror at her impending doom to a smile of gratitude as she gently floats to the ground in Superman's arms. The committee wants to know if there is really enough time to express this range of emotions, even if there is a possible academy award on the line. The chairman asks you to calculate the time it takes for Superman to stop Lois's fall. To do the calculation, you assume that Superman applies a constant force to Lois in breaking her fall and that she weighs 120 lbs. While thinking about this scene you also wonder if Lois could survive the force that Superman applies to her.

26. This year you have a summer job working for the National Park Service. Since they know that you have taken physics, they start you off in the laboratory which tests possible new equipment. Your first job is to test a small cannon. During the winter, small cannons are used to prevent avalanches in populated areas by shooting down heavy snow concentrations overhanging the sides of mountains. In order to determine the range of the cannon, it is necessary to know the velocity with which the projectile leaves the cannon (muzzle velocity). The cannon you are testing has a weight of 700 lbs. and shoots a 40-lb projectile. During the lab tests the cannon is held horizontally in a rigid support so that it cannot move. Under those conditions, you measure the magnitude of the muzzle velocity to be 400 m/s. When the cannon is actually used in the field, however, it is mounted so that it is free to move (recoil) when it is fired. Your boss asks you to calculate the projectile's speed leaving the cannon under field conditions, when it is allowed to recoil. She tells you to take the case where the cannon is fired horizontally using cannon shells which are identical to those used in the laboratory test.

27. You have been able to get a part time job with a medical physics group investigating ways to treat inoperable brain cancer. One form of cancer therapy being studied uses slow neutrons to knock a particle (either a neutron or a proton) out of the nucleus of the atoms which make up cancer cells. The neutron knocks out the particle it collides with in an inelastic collision. The heavy nucleus essentially does not move in the collision. After a single proton or neutron is knocked out of the nucleus, the nucleus decays, killing the cancer cell. To test this idea, your research group decides to measure the change of internal energy of a nitrogen nucleus after a neutron collides with one of the neutrons in its nucleus and knocks it out. In the experiment, one neutron goes into the nucleus with a speed of 2.0×10^7 m/s and you detect two neutrons coming out at angles of 30^o and 15^o. You can now calculate the change of internal energy of the nucleus.

Rotational Kinematics and Dynamics Problems

The problems in this section can be solved by applying rotational kinematics and dynamics principles. The problems are divided into four groups according to the major principles required for solution: (1) center of mass, moment of inertia, and/or rotational kinematics; (2) rotational energy; (3) torques; and (4) angular momentum. The specific principles required are indicated in italics at the beginning of each problem.

Center of Mass, Moment of Inertia, and Rotational Kinematics

1. *Center of Mass:* You have been hired as part of a research team consisting of biologists, computer scientists, engineers, mathematicians, and physicists investigating the virus which causes AIDS. This effort depends on the design of a new centrifuge which separates infected cells from healthy cells by spinning a container of these cells at very high speeds. Your design team has been assigned the task of specifying the mechanical structure of the centrifuge arm which holds the sample container. For aerodynamic stability, the arm must have uniform dimensions. Your team decided the shape will be a long, thin strip of length L, width w, and thickness t. The mass of the strip is M. The actual values of these quantities will be optimized by a computer program. For mechanical reasons, the arm must be stronger at one end than at the other. Your team decided to use new composite materials to accomplish this. Using these materials changes the strength by changing the density of the arm along its length while keeping its dimensions constant. To calculate the strength of the brackets necessary to support the arm, you must determine the position of the center of mass of the arm. You decide to do this in two different ways.
   (a) First you make a crude approximation of your design by assuming that the arm is a rigid, massless rod of length L. On this rod are mounted four small objects of equal mass. One of these objects is positioned at each end of the rod, one in the center of the rod, and one midway between the center and the end.
   (b) Next you do a more exact calculation by assuming that arm is a continuous material with a density which varies linearly along its length as (A + Bx).

2. *Center of Mass, Moment of Inertia:* You are on a development team investigating a new design for computer magnetic disk drives. You have been asked to determine if the standard disk drive motor will be sufficient for the test version of the new disk. To do this you decide to calculate how much energy is needed to get the 6.4 cm diameter, 15 gram disk to its operating speed of 350 revolutions per second. The test disk also has 4 different sensors attached to its surface. These small sensors are arranged at the corners of a square with sides of 1.2 cm. To assure stability, the center of mass of the sensor array is in the same position as the center of mass of the disk. The disk's axis of rotation also goes through the center of mass. You know that the sensors have masses of 1.0 grams, 1.5 grams, 2.0 grams, and 3.0 grams. The moment of inertia of your disk is one-half that of a ring.

   Center of Mass, Momentum, Kinematics: Two government agents (FBI agents Mulder and Scully) need your physics expertise to determine why an alien spaceship exploded. The wreckage of the spaceship is in three large pieces around a northern Minnesota town. The center of mass of one piece (mass = 300 kg) of the spaceship landed 6.0 km due north of the center of town. Another piece (mass = 1000 kg) landed 1.6 km to the southeast (36 degrees south of east) of the center of town. The last piece (mass = 400 kg) landed 4.0 km to the southwest (65 degrees south of west) of the center of town. There are no more pieces of the spaceship. The Army, which was watching the spaceship on its radar, claims it was hovering motionless over the center of town when the spaceship spontaneously exploded and the pieces fell to the ground. Agents Mulder and Scully do not believe that the spaceship exploded on its own accord. They think a missile hit it. They ask you to determine whether the fragments found are consistent with the spaceship exploding spontaneously. If not, determine from what direction the missile came. (For simplicity, assume that the pieces of the spaceship after the explosion are moving horizontally.)

4. *Kinematics, Moment of Inertia:* You are working in a research group investigating more energy efficient city busses. One option is to store energy in the rotation of a flywheel when the bus stops and then use it to accelerate the bus. The flywheel under consideration is disk of uniform construction except that it has a massive, thin rim on its edge. Half the mass of the flywheel is in the rim. When the bus stops, the flywheel needs to rotate at 20 revolutions per second. When the bus is going at its normal speed of 30 miles per hour, the flywheel rotates at 2 revolutions per second. The material holding the rim to the rest of the flywheel has been tested to withstand an acceleration of up to 100**g** but you are worried that it might not be strong enough. To check, you calculate the maximum radius of the rim for the case when the flywheel reaches 20 revolutions per second just as the bus going 30 miles per hour makes an emergency stop in 0.50 seconds. You assume that during this time the flywheel has a constant angular acceleration. Your trusty physics text tells you that the moment of inertia of a disk rotating about its center is half that of a ring of the same mass and radius.

5. *Kinematics, Force:* You did so well in your physics course that you decided to try to get a summer job working in a physics laboratory at the University. You got the job as a student lab assistant in a research group investigating the ozone depletion at the Earth's poles. This group is planning to put an atmospheric measuring device in a satellite which will pass over both poles. To collect samples of the upper atmosphere, the satellite will be in a circular orbit 200 miles above the surface of the Earth which has a radius of about 4000 miles. To adjust the instruments for the proper data taking rate, you need to calculate how many times per day the device will sample the atmosphere over the South pole.

6. *Kinematics, Force:* While listening to your professor drone on, you dream about becoming an engineer helping to design a new space station to be built in deep space far from any planetary systems. This state-of-the-(future) art station is powered by a small amount of neutron star matter which has a density of 2×10^{14} g/cm^3. The station will be a large light-weight wheel rotating about its center which contains the power generator. A control room is a tube which goes all the way around the wheel and is 10 meters from its center. The living space and laboratories are located at the outside rim of the wheel and are another tube which goes all the way around it at a distance of 200 meters from the center. To keep the environment as normal as possible, people in both the outer rim and the control room should experience the same “weight” as they had on Earth. That is if they were standing on a bathroom scale, it would read the same as if they were on Earth. This is accomplished by a combination of the rotation of the station and the gravitational attraction of the neutron star matter in the power generator. You suddenly wake up when you drop your pen but decide that the idea is interesting enough to calculate the necessary rate of rotation and generator mass. While drawing the free-body diagrams, you realize that the people are standing with their heads inward on the rim of the station and with their heads outward in the control room.

7. *Kinematics, Force:* You have a summer job at NASA where your team is responsible for specifying a rocket to lift a communications satellite into a circular orbit around the Earth. To effectively relay signals, the satellite will have to always remain over the same point on the Earth's equator just above the communications station which is located 50 miles outside or Nairobi, Kenya. The satellite will have a mass of 3500 kg. You have been assigned the task of calculating the radius of the satellite's orbit and its

speed while in orbit and presenting that calculation to your team. For your own curiosity you also decide to calculate the force that the satellite exerts on the Earth while it is in orbit. From your trusty physics textbook you find the radius of the Earth is 6370 km, its mass is 5.96 x 10^{24} kg, and the universal gravitational constant is 6.67 x 10^{-11} N m^2/kg^2.

Rotational Energy

8. *Energy:* While working in an environmental engineering team to determine the quality of the air in downtown Minneapolis, you have been given the task of calibrating the spectrum analyzer. This device gives you the composition of the gasses in a sample by determining the frequency of light absorbed by the sample. Each type of molecule absorbs a certain set of frequencies (its spectrum). The frequencies actually measured are changed if the molecules have an angular velocity about their center of mass. To calibrate the analyzer, you must calculate the expected angular velocity for the Oxygen molecules (O2) in the sample of Minneapolis air. At the temperatures of your gas sample, you calculate that the center of mass speed of a typical molecule is 500 m/s. Based on you knowledge of atomic sizes, you estimate that the typical distance between the nuclei of oxygen atoms in the molecule is 10^{-8} cm. You also know that the 27 x 10^{-27} kg mass of an Oxygen atom is essentially concentrated in its very small nucleus. Your boss tells you to assume that the rotational kinetic energy of the molecule rotating about an axis through the center of the line joining the nuclei of the atoms and perpendicular to that line is 2/3 its translational kinetic energy.

9. *Energy:* While working on your latest novel about settlers crossing the Great Plains in a wagon train, you get into an argument with your co-author regarding the moment of inertia of an actual wooden wagon wheel. The 70-kg wheel is 120-cm in diameter and has heavy spokes connecting the rim to the axle. Your co-author claims that you can approximate using $I = MR^2$ (like for a hoop) but you anticipate I will be significantly less than that because of the mass located in the spokes. To find I experimentally, you mount the wheel on a low-friction bearing then wrap a light cord around the outside of the rim to which you attach a 20-kg bag of sand. When the bag is released from rest, it drops 3.77-m in 1.6-s during which time the wheel rotates through an angle of 2p-radians. Hint: Use energy considerations.

10. *Energy:* You have a summer job helping to design the opening ceremony for the next winter Olympics. One of the choreographer's ideas is to have skaters race out onto the ice and grab a very large ring (the symbol of the Olympics). Each ring is held horizontal at shoulder height by a vertical pole stuck into the ice. The pole is attached to the ring on its circumference so that the ring can rotate horizontally around the pole. The plan is to have the skater grab the ring at a point on the opposite side from where the pole is attached and, holding on, glide around the pole in a circle. You have been assigned the job of determining the minimum speed that the skater must have before grabbing the ring in terms of the radius of the ring, the mass of the ring, the mass of the skater, and the constant frictional force between the skates and the ice. The choreographer wants the skater and ring to go around the pole at least five times. The skater is to be moving tangent to the ring just before grabbing it.

Energy, Center of Mass: As a project your team is given the task of designing a space station consisting of four different habitats. Each habitat is an enclosed sphere containing all necessary life support and laboratory facilities. The masses of these habitats are 10 x 10^5 kg, 20 x 10^5 kg, 30 x 10^5 kg, and 40 x 10^5 kg. The entire station must spin so that the inhabitants will experience an artificial gravity. Your team has decided to arrange the habitats at corners of a square with 1.0 km sides. The axis of rotation will be perpendicular to the plane of the square and through the center of mass. To help decide if this plan is practical, you calculate how much energy would be necessary to set the space station spinning at 5.0 revolutions per minute. In your team's design, the size of each habitat is small compared to the size of the space between the habitats and the structure that holds the habitats together is much less massive than any single habitat.

12. *Energy, Center of Mass:* You have a great summer job working for a movie studio. Your assignment is to check the script of an upcoming Star Wars movie for scientific accuracy. In one scene, the hero escapes by putting her spaceship through a wormhole in space. The engines have failed so the ship is coasting when it emerges in another part of the galaxy at the center of a binary star system. Both stars in the system orbit their center of mass and have equal mass. You need to determine the minimum speed of the spaceship when it emerges from the wormhole perpendicular to the plane of the orbiting stars so that it is not captured by the star system. When the movie is better defined, you will know the mass of each star, the radius of their orbit, and the mass of the spaceship. You assume that even a long time ago in a galaxy far, far away the gravitational constant is the same.

13. *Energy, Forces:* You have applied for a great summer job working with a special effects team at a movie studio. As part of your interview you have been asked to evaluate the design for a stunt in a new Indiana Jones production. A large spherical boulder starts from rest and rolls down an inclined track. At the bottom, the track curves up into a vertical circle so that the boulder can roll around on the inside of the circle and come back to ground level. It is important that the boulder not fall off the track at the top of the circle and crush the star standing below. You have been asked to determine the relationship between the height of the boulder's starting point on the ramp (measured from the center of the boulder) and the maximum radius the circular part of the track. You can determine the mass and the radius of the boulder should you need to know them. You have also been told that the moment of inertia of a sphere is 2/5 that of a ring of the same mass and radius. After some thought you decide that the boulder will stay moving in a vertical circle if its radial acceleration at the top is just that provided by gravity.

Torques

14. *Torque:* In a budget cutting move, the University decided to replace their human mascot, Goldie Gopher, by a real gopher. Unfortunately the new 10 lb Goldie has other ideas and has escaped the clutches of the athletic department by jumping out a window onto a flagpole attached to the building. The fire department has been called in to recover the recalcitrant gopher. The plan is for a fireman to climb out on the flagpole and get Goldie. Goldie is 3 meters out on the 4 meter long flagpole. Because of your technical background, you have a part time job as a University safety officer and are asked to approve this plan. The pole is attached to the building at an angle of 37° above the horizontal and weighs 22 lbs. A horizontal cable with a rated strength of 300 lbs. connects the far end of the pole to the building seems strong enough. The other end of the pole is connected to the building by a steel pin supported by a strong steel brace.
You are worried about whether this pin is strong enough so you calculate the forces on the pin. The lightest fireman available for the job of getting Goldie weighs 150 lbs. in all of her gear. You find that the pin is strong enough so you might approve this daring rescue. You want it to be as safe as possible. You will require that the fireman wear a safety harness which is held by someone inside the building. After all, the cable holding up the flagpole has been out in the Minnesota winter for years. If the cable does break, the flagpole will rotate about the pin supporting its base.
Doing a quick integral, you find that the moment of inertia of a pole about an axis at one end is 1/3 as much as if all its mass were concentrated at the other end of the pole. To save the fireman you must get her off before the pole goes below a horizontal orientation. The gopher will be on its own. To see if

rescue is possible, you calculate the acceleration of the flagpole with the fireman and gopher clinging to it for the two extreme cases, just after the cable breaks and just as it reaches a horizontal orientation.

15. *Torque:* The automatic flag raising system on a horizontal flagpole attached to the vertical outside wall of a tall building has become stuck. The management of the building wants to send a person crawling out along the flagpole to fix the problem. Because of your physics knowledge, you have been asked to consult with a group to decide whether or not this is possible. You are all too aware that no one could survive the 250 foot fall from the flagpole to the ground. The flagpole is a 120 lb steel I-beam which is very strong and rigid. One side of the flagpole is attached to the wall of the building by a hinge so that it can rotate vertically. Nine feet away, the other end of the flagpole is attached to a strong, lightweight cable. The cable goes up from the flagpole at an angle of 30° until it reaches the building where it is bolted to the wall. The mechanic who will climb out on the flagpole weighs 150 lbs. including equipment. From the specifications of the building construction, both the bolt attaching the cable to the building and the hinge have been tested to hold a force of 500 lbs. Your boss has decided that the worse case is when the mechanic is at the far end of the flagpole, nine feet from the building.

16. *Torque:* After watching a news story about a fire in a high rise apartment building, you and your friend decide to design an emergency escape device from the top of a building. To avoid engine failure, your friend suggests a gravitational powered elevator. The design has a large, heavy turntable (a horizontal disk that is free to rotate about its center) on the roof with a cable wound around its edge. The free end of the cable goes horizontally to the edge of the building roof, passes over a heavy vertical pulley, and then hangs straight down. A strong wire cage which can hold 5 people is then attached to the hanging end of the cable. When people enter the cage and release it, the cable unrolls from the turntable lowering the people safely to the ground. To see if this design is feasible you decide to calculate the acceleration of the fully loaded elevator to make sure it is much less than g. Your friend's design has the radius of the turntable disk as 1.5 m and its mass is twice that of the fully loaded elevator. The disk which serves as the vertical pulley has 1/4 the radius of the turntable and 1/16 its mass. In your trusty Physics book you find that the moment of inertia of a disk is 1/2 that of a ring.

17. *Torques, Kinematics:* Because of your physics background, you have been asked to be a stunt consultant for a motion picture about a genetically synthesized prehistoric creature that escapes from captivity and terrorizes the city. The scene you are asked to review has the three main characters of the movie being chased by the creature through an old warehouse. At the exit of the warehouse is a thick steel fire door 10 feet high and 6.0 feet wide weighing about 2,000 pounds. In the scene, the three actors are to flee from the building and close the fire door (initially at rest), thus sealing the creature inside the building. With the creature running at 30 mph, they have 5.0 seconds to shut the door. You are asked to determine if they can do it. You estimate that each actor can each push on the door with a force of 50 pounds. When they push together, each actor needs a space of about 1.5 feet between them and the next actor. The door, which has a moment of inertia of $1/3\ M\ r^2$ around its hinges, needs to rotate 120 degrees for it to close completely.

18. *Torque, Kinematics:* While watching the local TV news show, you see a report about ground water contamination and how it effects farms which get their water from wells. For dramatic effect, the reporter stands next to an old style well which still works by lowering a bucket at the end of a rope into a deep hole in the ground to get water. At the top of the well a single vertical pulley is mounted to help raise and lower the bucket. The thin rope passes over the large pulley which is essentially a heavy steel ring supported by light spokes. To demonstrate the depth of the well, the reporter completely wraps the rope around the pulley and suspends the bucket from one end. She then releases the bucket, at rest near the pulley, and it descends to the bottom of the well unwinding the rope from the pulley as it falls. It

takes 2.5 seconds. She doesn't tell you the depth of the well so you decide to calculate it. You estimate that the pulley has the same mass of the bucket and assume that the mass of the rope and any friction can be neglected.

19. *Energy or Torques, Kinematics:* While you watching a TV show about life in the ancient world, you see that the people in one village used a solid sphere made out of clay as a kind of pulley to help haul up water from a well. A well-greased wooden axle was placed through the center of the sphere and fixed in a horizontal orientation above the well, allowing the sphere to rotate freely. To demonstrate the depth of the well, the host of the program completely wrapped the rope around the sphere and suspended the bucket from one end. She then released the bucket, at rest near the sphere, and allowed it to descend to the bottom of the well unwinding the string from the sphere as it went. It took 2.5 seconds. You wonder what the depth of the well was so you decide to calculate it. You estimate that the sphere has twice the mass of the bucket and assume that the mass of the rope can be neglected. You look up the moment of inertia of a sphere about an axis through its center of mass and find it is 2/5 that of a ring of the same mass and radius.

20. *Energy or Torque, Kinematics:* You have been asked to help design a safety mechanism which will automatically drops a rope from the window of an apartment in the case of fire. One end of the rope is fastened to a ledge on the outside wall of the building while the other is rolled tightly around a hollow cylinder. When a fire is detected, the mechanism drops the hollow cylinder so that it is parallel to the ground. The cylinder falls straight down without touching the side of the building and the rope unwinds from around a point midway along its length. To optimize your design, you need to calculate how long it takes to fall to the ground as a function of the height of the fall, the radius of the cylinder, the mass of the cylinder, and the length of the cylinder.

21. *Torques, Forces:* A friend of yours who likes to fix his own car has improvised a car-lifting device in his garage. He explains that he plans to park the car on a rectangular platform which is lifted into the air by four ropes each attached to a corner of the platform. The platform is constructed of steel I-beams and has a weight of 250 lbs. It is 12 feet long and 5.0 feet wide with its center of mass 5.0 feet from the front and 2.5 feet from either side. His car has a weight of 1400 lbs. and 75% of that weight is carried by the front tires. The distance between the centers of the tires is 7.2 feet. His plan is to park the car in the middle of the platform with the front tire 2.4 feet from the front of the platform over the midpoint of the platform. In that way, the two front ropes have the equal tensions and the two back ropes will also have equal tensions. The ropes are certified to hold a load of 5000 N each. Before he uses his device, he has asked your advice on its safety.

22. *Torques, Forces:* You have been asked to design a machine to move a large cable spool up a factory ramp in 30 seconds. The spool is made of two 6.0 ft diameter disks of wood with iron rims connected together at their centers by a solid cylinder 1.0 ft wide and 3.0 ft long. Sometime later in the manufacturing process, cable will be wound around the cylinder. For now the cylinder is bare but the spool still weighs 200 lbs. Your plan is to attach a thin ring around the cylinder and pull the spool up the ramp with a rope attached to the top of this ring. The spool will then roll without slipping up the ramp on its two outside disks at a constant speed. To finish the design you need to calculate how strong the rope must be to pull the spool when it is moving up the ramp at a constant speed. The ramp has an angle of 27^o from the horizontal and the rope will be parallel to the ramp. A set of light weight bearings minimizes the friction between the ring and the cylinder and fixes the orientation of the ring so that the rope always pulls from its top. The diameter of the ring is essentially the same as that of the cylinder.

23. *Torques, Forces:* You have been chosen to be part of a team investigating an explosion in a virology laboratory. When you enter the lab, you see that a large utility conduit, which was originally suspended horizontally overhead, has fallen on top of a chemical workbench. You decide to determine if a mechanical failure made the conduit break, crashing into the chemicals and causing the explosion or if the chemical explosion caused the conduit to fall. The heavy conduit, essentially a bar with a non-uniform mass distribution, was held up in the air by two lightweight cables attached to the ceiling at different angles. One cable was attached at each end of the conduit. To check out the possibility of a mechanical failure, you first decide to calculate the position of the center of mass from one end of the conduit based on the known weight of the conduit, the length of the conduit, and the angles of the cables with the ceiling.

24. *Torques, Forces:* You have a summer job working downtown washing windows on skyscrapers (the pay is great and so are the medical benefits). The platform you and your partner are using to get to the windows is a meter wide and four meters long. You know from hauling the platform out of your truck countless times that it has a mass of 70 kg. It is supported by two cables, one at each end, mounted on-center to prevent the platform from tipping over as it is pulled up the side of the building at a constant speed. If you (mass of 55 kg) are standing on the platform 1 meter from one cable while your partner (mass of 87 kg) is 1.3 meters from the other cable and both of you are half a meter from the side, what is the tension in each cable? Assume the platform has a uniform mass distribution and is of negligible thickness.

Angular Momentum

25. *Angular Momentum:* You are part of a team in an engineering contest trying to design a mechanical "cat" which, when dropped motionless, upside down from 2.5 m, can right itself before it hits the ground by rotating its "tail." The body of the "cat," aptly named Katt, is a solid cylinder 1 foot in length and 6 inches in diameter, with a mass of 5.44 kg. Attached to the center of one end of the body is Katt's "tail," a 1 foot long rod which extends out perpendicular to Katt's body and has only 1% the mass of the body. Your task is to determine the energy demand put on the small electric motor in the body which rotates the "tail." Based on your work, have you any design improvements to suggest to the rest of the team? Remember: a solid cylinder rotated about it's central axis has a moment of inertia 1/2 that of a cylinder with all it's mass on it's circumference; a rod rotated about one end has a moment of inertia 1/3 of that if mass were concentrated at the opposite end.

26. *Angular Momentum:* You have been asked to help evaluate a proposal to build a device to determine the speed of hockey pucks shot along the ice. The device consists of a rod which rests on the ice and is fastened to the ice at one end so that it is free to rotate horizontally. The free end of the rod has a small, light basket which will catch the hockey puck. The puck slides across the ice perpendicular to the rod and is caught in the basket which is initially at rest. The rod then rotates. The designers claim that knowing the length of the rod, the mass of the rod, the mass of the puck, and the frequency of the rotation of the rod and puck, you can determine the speed of the puck as it moved across the ice.

27. *Angular Momentum, Energy:* You are a member of a group designing an air filtration system for allergy suffers. To optimize its operation you need to measure the mass of the common pollen in the air where the filter will be used. To measure the pollen’s mass, you have designed a small rectangular box with a hole in one side to allow the pollen to enter. Once inside the pollen is given a positive electric charge and accelerated by an electrostatic force to a speed of 1.4 m/s. The pollen then hits the end of a very small, uniform bar which is hanging straight down from a pivot at its top. Since the bar has a

negative charge at its tip, the pollen sticks to it as the bar swings up. Measuring the angle that the bar swings up would give the particle's mass. After the angle is measured, the charge of the bar is reversed, releasing that particle. It's a cool design but your friend insists it will never work. To prove it she asks you to calculate the length of the bar which would give you a reasonable angle of about 10° for a typical pollen particle of 4 x 10^{-9} grams. Your plan calls for a bar of 7 x 10^{-4} grams with a moment of inertial 1/12 as much as if all of its mass were concentrated at its end. Is she right?

28. *Angular Momentum, Energy:* You have been asked to design a new stunt for the opening of an ice show. A small 50 kg skater glides down a ramp and along a short level stretch of ice. While gliding along the level stretch she makes herself as small as possible. Keeping herself as small as possible she then grabs the bottom end of a large 180 kg vertical rod which is free to turn vertically about a axis through its center. The plan is for her to hold onto the 20 foot long rod while it swings her to the top. The rod has a uniform mass distribution. You have been asked to give the minimum height of the ramp. Doing a quick integral tells you that the moment of inertia of this rod about its center is 1/3 of what its moment of inertia would be if all of its mass were concentrated at one of its ends.

29. *Angular Momentum, Energy:* Your group has decided to revisit the lab experiment in which a metal ring was dropped onto a rotating plate. In hopes of getting better results, you now have a motor which initially spins the disk and shaft at 3.0 rev. per second. You are also using a mechanical device to drop the ring, so that it lands perfectly in the groove on every trial. Unfortunately the bearing in your apparatus is giving out (after weeks of heavy use) so you must redo your analysis, taking into account the frictional force which the bearing applies to the outside of the shaft. You assume that this force is approximately constant, except perhaps during the collision event itself. To avoid the large uncertainties associated with using a stopwatch, you decide to count revolutions -- you let the disk rotate twice after disengaging the motor, then drop the ring, then note that the entire apparatus goes around 17 more times before coming to rest. How large is the frictional force? The radii of the disk, shaft, and ring are 11 cm, 0.63 cm, and 6.5 cm (5.5 cm) outside (inside) respectively. The moments of inertia (about the appropriate axis) for the disk, shaft, and ring are 5.1 x 10^{-3} kg m^2, 3.7 x 10^{-6} kg m^2, and 8.9 x 10^{-3} kg m^2 respectively.

30. *Angular Momentum, Energy, Kinematics:* You have been hired by a company which is designing a new water slide for an amusement park . The conceptual design has a customer going down a curved slide ending up moving horizontally at the bottom. At the end of the of the slide, the customer grabs the end of a 16.0 m long vertical bar that is free to pivot about its center. After grabbing onto the bar, the customer swings out over a pool of water. When the bar swings out to its maximum distance, the customer can drop off and fall straight down into the water. Your task is to determine the height of the slide so that the maximum horizontal distance that the bar swings out is 5.0 m for a 60 kg person. The bar has five times the mass of a 60 kg person. From an engineering handbook, you find that the moment of inertia of the bar is 1/12 of what it would be if all of its mass were concentrated at the bottom.

Conservation of Energy and Heat Problems
(Beginning Thermodynamics)

1. To take a break from studying physics, you rent the video of the movie version of the book *Fahrenheit 451*, which stared Oscar Werner. The setting (in England) is an Orwellian society where books are banned and all information is disseminated by a large TV screen in each home. Fire departments respond not to put out fires, but to burn books, which combust at a temperature of 451 ^oF (hence the name of the film). In the middle of the film, your mind wanders. You imagine the fire department using the burning books to heat 600 cm^3 of water for their afternoon tea. You imagine that the burner transfers 80% of the heat from the burning books to the water, which you remember has a heat capacity of 1.0 calorie/g ^oC. How much will the water temperature rise from burning one copy of the 500-page book *Fahrenheit 451* if the heat of combustion is 1.0 calorie per page?

2. You are helping a friend who is a veterinarian to do some minor surgery on a cow. She has asked you to sterilize a scalpel and a hemostat by boiling them for 30 minutes. You boil them as ordered and then quickly transfer the instruments to a well insulated tray containing 200 grams of sterilized water at room temperature (23 ^oC) which is just enough to cover the instruments. After a few minutes the instruments and water will come to the same temperature, but will they be safe to hand to your friend without being burned? You are both wearing surgical rubber gloves, but they are very thin. You know that both the 50 gram scalpel and the 70 gram hemostat are made from steel which has a specific heat of 450 J / (kg ^oC). They were boiled in 2.0 kg of water with a specific heat of 4200 J / (kg ^oC).

3. You have a summer job with a company that designs cookware. Your group is assigned the task of designing a better pasta pot. You are very excited by a new strong, light alloy the group has just produced, but will it make a good pasta pot? If it takes more than 10 minutes to boil water in a pasta pot, it probably won't sell. So your boss asks you to calculate how long it would take water at room temperature (23 ^oC) to reach boiling temperature (100 ^oC) in a pot made of the new alloy. Your colleagues tell you that a typical pasta pot holds about 2 liters (2.0 kg) of water. They estimate that a pot made of the alloy would have a mass of 550 grams, and a specific heat capacity of 860 J / (kg ^oC). You look in your physics book and find that water has a specific heat capacity of 4200 J / (kg ^oC) and its heat of vaporization is 2.3×10^6 J/kg. The owner's manual states that the burners on your stove deliver 1000 Joules of heat per second. You estimate that only about 20% of this heat is radiated away.

4. You are planning a birthday party for your niece and need to make at least 4 gallons of Kool-Aid, which you would like to cool down to 32 ^oF (0 ^oC) before the party begins. Unfortunately, your refrigerator is already so full of treats that you know there will be no room for the Kool-Aid. So, with a sudden flash of insight, you decide to start with 4 gallons of the coldest tap water you can get, which you determine is 50 ^oF (10 ^oC), and then cool it down with a 1-quart chunk of ice you already have in your freezer. The owner's manual for your refrigerator states that when the freezer setting is on high, the temperature is -20 ^oC. Will your plan work? You assume that the density of the Kool-Aid is about the same as the density of water. You look in your physics book and find that the density of water is 1.0 g/cm^3, the density of ice is 0.9 g/cm^3, the heat capacity of water is 4200 J / (kg ^oC), the heat capacity of ice is 2100 J / (kg ^oC), the heat of fusion of water is 3.4×10^5 J/kg, and its heat of vaporization is 2.3×10^6 J/kg.

5. You are thinking ahead to spring when one of your friends is having an outdoor wedding. Your plan is to design the perfect lemonade for the event. The problem with lemonade is that you make it at room temperature and then add ice to cool it to a pleasant 10 °C. Usually, the ice melts diluting the lemonade too much. To help you solve this problem, you look up the specific heat capacity of water (1.0 cal/(gm °C)), the specific heat capacity of ice (0.50 cal/(gm °C)), and the latent heat of fusion of water (80 cal/gm). You assume that the specific heat capacity of the lemonade is the same as water. Since you will cool your lemonade in a Thermos jug, assume no heat is added to the lemonade from the environment. Using that information, you calculate how much water you get from all the ice melting if you make 6 quarts (5.6 kg) of lemonade at room temperature (23 °C) and add ice which comes straight from the freezer at -5.0 °C.

6 While working for a grain loading company over the summer, your boss asks you to determine the efficiency of a new type of pneumatic elevator. The elevator is supported in a cylindrical shaft by a column of air, which you assume to be an ideal gas with a specific heat of 12.5 J/mol-°C. The air pressure in the column is 1.2×10^5 Pa when the elevator carries no load. The bottom of the cylindrical shaft opens out so that there is a reservoir of air at room temperature (25° C) below the elevator when it begins loading. Seals around the elevator assure that no air escapes as the elevator moves up and down. The elevator has a cross-sectional area of 10 m^2. A cycle of elevator use begins with the unloaded elevator. The elevator is then loaded with 20,000 kg of grain while the air temperature stays at 25° C causing the elevator to sink. The air in the system is then heated to 75° C and the elevator rises. The elevator is then unloaded, while the air remains at 75° C. Finally, the air in the system is cooled to room temperature again, returning the elevator to its starting level. While the elevator is moving up and down, you assume that it moves at a constant velocity so that the pressure in the gas is constant.

7. Note: This problem requires both mechanical energy and heat energy for a solution. In the class demonstration, a 2.0-gram lead bullet was shot into a 2.0-kg block of wood. The block of wood with the bullet stuck in it was hung from a string and rose to a height 0.50 cm above its initial position. From that information we calculated that the initial speed of the bullet was about 300 m/s (close to the speed of sound). What was the bullet like when it stopped? Using conservation of energy and conservation of momentum, we decided that the internal energy of the bullet, block system had increased substantially. If the change of internal energy of the bullet was half that of the system, would this change be enough to melt the bullet? Assume that the bullet had a temperature of 50 ^oC when it left the gun. The melting temperature of lead is 330 ^oC. It has a specific heat capacity of 130 J/(kg ^oC) and a latent heat of fusion of 25 J/g. The specific heat capacity of wood is 1700 J/(kg ^oC).

Oscillations and Waves Problems

1. *Oscillation:* You have been asked to evaluate the design for a simple device to measure the mass of small rocks on the Moon. The rock is attached to the free end of a lightweight spring which horizontal. The surface on which the rock slides is almost frictionless. You are worried that the kinetic energy of the rock may make this device dangerous in some situations. The device specifications state that a 150 gram rock will execute harmonic motion, with a frequency of 0.32 Hz, described by $x(t) = A \sin (bt - 35°)$ when the rock has an initial speed of 1.2 cm/s.

3. *Oscillations:* You and some friends are waiting in line for "The Mixer", a new carnival ride. The ride begins with the car and rider (150 kg combined) at the top of a curved track. At the bottom of the track is a 50 kg block of cushioned material which is attached to a horizontal spring whose other end is fixed in concrete. The car slides down the track ending up moving horizontally when it crashes into the cushioned block, sticks to it, and oscillates at 3 repetitions in about 10 seconds. Your friends estimate that the car starts from a height of around 10 feet. You decide to use your physics knowledge to see if they are right. After the collision, you notice that the spring compresses about 15 ft from equilibrium.

3. *Traveling Waves:* You've been hired as a technical consultant to the Minneapolis police department to design a radar detector-proof device that measures the speed of vehicles. (i.e. one that does not rely on sending out a radar signal that the car can detect.)

   You decide to employ the fact that a moving car emits a variety of characteristic sounds. Your idea is to make a very small and low device to be placed in the center of the road that will pick out a specific frequency emitted by the car as it approaches and then measure the change in that frequency as the car moves off in the other direction. The device will then send the initial and final frequencies to its microprocessor, and then use this data to compute the speed of the vehicle.

   You are currently in the process of writing a program for the chip in your new device. To complete the program, you need a formula that determines the speed of the car using the data received by the microprocessor. You may also include in your formula any physical constants that you might need.

   Because your reputation as a designer is on the line, you realize that you'll need find ways to check the validity of your formula, even though it contains no numbers.

4. *Traveling Waves:* You have the perfect summer job with a team of marine biologists studying dolphin communication off the coast of Hawaii. Massive boulders on the ocean floor can interrupt the reception of underwater sound waves from the dolphins. To reduce these disruptions, your team has decided to put several "transceivers" (a device that receives a signal, amplifies the signal, and then transmits it) at strategic locations on the ocean floor. A transceiver will receive sound waves from a dolphin and then retransmit them to the researchers on the ship. The ship's receiver is on a long cable so that it is at approximately the same depth as the dolphins. Because of your physics background, you worry that the frequency received at the moving ship will be different than that emitted by the dolphin. To determine the size of this effect, you assume that the ship is moving at 35km/h away from the stationary transceiver. Meanwhile, the dolphin is moving at 60km/h towards the transceiver and at an angle of 63° to the ship's path when it emits a sound frequency of 660Hz.

5. *Wave Equation:* A friend of yours, a guitarist, knows you are taking physics this semester and asks for assistance in solving a problem. Your friend explains that he keeps breaking repeatedly the low E string

(640 Hz) on his Gibson "Les Paul" when he tunes-up before a gig. The cost of buying new strings is getting out of hand, so your friend is desperate to resolve his Delia. Your friend tells you that the E string he is now using is made of copper and has a diameter of 0.063 inches. You do some quick calculations and, given the length of the neck of your friends guitar, estimate that the wave speed on the E string is 1900 ft/s. While reading about stringed instruments in the library, you discover that most musical instrument strings will break if they are subjected to a strain greater than about 2%. How do you suggest your friend solve his problem?

6. *Standing Waves:* Your friend, an artist, has been thinking about an interesting way to display a new wind sculpture she has just created. In order to create an aural as well as visual effect, she would like to use the wires needed to hang the sculpture as a sort of a string instrument. She decides that with three wires and some luck, the strings will sound a C-major dyad (C - 262Hz, G - 392 Hz) when the wind blows (note: A dyad is part of a chord.). Her basic design involves attaching a piece of wire from two eye-hooks on the ceiling that are approximately a foot-and-a-half apart and then hanging the 50 pound sculpture from another wire attached to the first wire forming a "y-shaped" arrangement. Your friend tells you that she has been successful in hanging the sculpture but not in "tuning" the sound. Desperate for success, she knows you are taking physics and asks for your help. Before you tackle the analysis, you use your knowledge of waves to gather some more information. You take a sample of the wire back to your lab and measure its linear mass density to be 5.0 g/m. You also determine that wire is some sort of iron or steel from its color. What is your advice?

7. *Standing Waves:* You have a summer job in a biomedical engineering laboratory studying the technology to enhance hearing. You have learned that the human ear canal is essentially an air filled tube approximately 2.7 cm long which is open on one end and closed on the other. You wonder if there is a connection between hearing sensitivity and standing waves so you calculate the lowest three frequencies of the standing waves that can exist in the ear canal. From your trusty Physics textbook, you find that the speed of sound in air is 343 m/s.

8. *Standing Waves:* You have joined a team designing a new skyway that is to link the Physics Building to the Mechanical Engineering Building. To make sure it will be stable in gusts of wind, you need to find the lowest frequency that sets up a standing wave in the skyway structure. Your group has decided to make a scale model of the skyway and put it into a wind tunnel to determine the frequency. Unfortunately the wind tunnel cannot be pulsed at a very low frequency. While the model is in the wind tunnel you pulse the wind until you find a frequency which sets up a standing wave in the model. You then slowly increase the frequency until you get the next standing wave pattern. Using the two frequencies you have measured together with the length of the skyway model you then calculate the lowest frequency which will set up a standing wave.

9. *Energy, Frequency:* You have an exciting summer job working on an oil tanker in the waters of Alaska. Your Captain knows that the ship is near an underwater outcropping of land and wishes to avoid running into it. He estimates that it is about 6 km straight ahead of the ship and asks you to use the sonar to check how fast the ship is approaching it. The ship's instruments tell you the ship is moving through still water at a speed of 31 km/hr but the captain cannot take any chances. A sonar signal is sent out with a frequency of 980 Hz, bounces off the underwater obstacle, and is detected on the ship. If the ship's speed indicator is correct, what frequency should you detect? You use your trusty Physics text to find the speed of sound in sea water is 1522 m/s.

10. *Rotations:* You are helping a friend build an experiment to test behavior modification techniques on rats. She needs to build an obstacle that swings across a path every 1.0 second. To keep the experiment as inexpensive as possible, she wants to use a meter stick as the swinging obstacle. She asks you to determine where to drill a hole in the meter stick so that, when it is hung by a nail through that hole, it will do the job for small swings.

11. *Rotations:* Your friend is trying to construct a clock for a craft show and asks you for some advice. She has decided to construct the clock with a pendulum. The pendulum will be a very thin, very light wooden bar with a thin, but heavy, brass ring fastened to one end. The length of the rod is 80 cm and the diameter of the ring is 10 cm. She is planning to drill a hole in the bar to place the axis of rotation 15 cm from one end. She wants you to tell her the period of this pendulum.

12. *Rotations:* The child of a friend has asked you to help with a school project. She wants to build a clock from common materials. She has found a meter stick which has a mass of 300g and asks you to determine where to drill a hole in it so that when it is hung by a nail through that hole it will be a pendulum with a period of 2.0 seconds for small oscillations. A quick calculation tells you that the moment of inertia of the meter stick about its center of mass is 1/12 of its mass times the square of its length.

13. *Rotations:* You have a part time job at a software company that is currently under contract to produce a program simulating accidents in the modern commuter railroad station being planned for downtown. Your task is to determine the response of a safety system to prevent a railroad car from crashing into the station. In the simulation, a coupling fails causing a passenger car to break away from a train and roll into the station. Furthermore, the brakes on the passenger car have failed. It cannot stop on its own so it keeps on rolling. The safety system at the end of the track is a large horizontal spring with a hook that will grab onto the car when it hits preventing the car from crashing into the station platform. After the car hits the spring, your program must calculate the frequency and amplitude of the car's oscillation based on the specifications of the passenger car, the specifications of the spring, and the speed of the passenger car. In your simulation, the wheels of the car are disks with a significant mass and a moment of inertia half that of a ring of the same mass and radius. At this stage of your simulation, you ignore any energy dissipation in the car's axle or in the flexing of the spring, and the mass of the spring.

14. *Rotations:* You have been asked to help design an automated system for applying a resistive paint to plastic sheeting in order to mass produce containers to protect sensitive electronic components from static electric charges. The object used to apply the paint is a solid cylindrical roller. The roller is pushed back and forth over the plastic sheeting by a horizontal spring attached to a yoke, which in turn is attached to an axle through the center of the roller. The other end of the spring is attached to a fixed post. To apply the paint evenly, the roller must roll without slipping over the surface of the plastic. The machine simultaneously paints two narrow strips of plastic that lay side by side parallel to the axle of the roller. While the roller is in contact with one strip, a feed mechanism pulls the other strip forward to expose unpainted surface. In order to determine how fast the process can proceed, you have been assigned to calculate how the oscillation frequency of the roller depends on its mass, radius and the stiffness of the spring. You know that the moment of inertia of a solid cylinder with respect to an axis through its center is 1/2 that of a ring.

Electricity and Magnetism Problems

Concepts and principles from electricity and magnetism can solve the problems in this section. The problems are divided into five groups according to the major principles required for solution: (1) electric force and field; (2) electric potential energy; (3) electric power; (4) circuits; and (5) magnetic force and field. The specific principles required are indicated in Italics at the beginning of each problem.

Electric Force and Field

1. *Electric Force:* You and a friend are doing the laundry when you unload the dryer and the discussion comes around to static electricity. Your friend wants to get some idea of the amount of charge that causes static cling. You immediately take two empty soda cans, which each have a mass of 120 grams, from the recycling bin. You tie the cans to the two ends of a string (one to each end) and hang the center of the string over a nail sticking out of the wall. Each can now hangs straight down 30 cm from the nail. You take your flannel shirt from the dryer and touch it to the cans, which are touching each other. The cans move apart until they hang stationary at an angle of 10° from the vertical. Assuming that there are equal amounts of charge on each can, you now calculate the amount of charge transferred from your shirt.

2. *Electric Force:* You are part of a design team assigned the task of making an electronic oscillator that will be the timing mechanism of a micro-machine. You start by trying to understand a simple model which is an electron moving along an axis through the center and perpendicular to the plane of a thin positively charged ring. You need to determine how the oscillation frequency of the electron depends on the size and charge of the ring for displacements of the electron from the center of the ring which are small compared to the size of the ring. A team member suggests that you first determine the acceleration of the electron along the axis as a function of the size and charge of the ring and then use that expression to determine the oscillation frequency of the electron for small oscillations.

3. *Electric Force:* You are spending the summer working for a chemical company. Your boss has asked you to determine where a chlorine ion of effective charge -e would situate itself near a carbon dioxide ion. The carbon dioxide ion is composed of 2 oxygen ions each with an effective charge -2e and a carbon ion with an effective charge +3e. These ions are arranged in a line with the carbon ion sandwiched midway between the two oxygen ions. The distance between each oxygen ion and the carbon ion is 3.0×10^{-11} m. Assuming that the chlorine ion is on a line that is perpendicular to the axis of the carbon dioxide ion and that the line goes through the carbon ion, what is the equilibrium distance for the chlorine ion relative to the carbon ion on this line? For simplicity, you assume that the carbon dioxide ion does not deform in the presence of the chlorine ion. Looking in your trusty physics textbook, you find the charge of the electron is 1.60×10^{-19} C.

4. *Electric Force:* You have been asked to review a new apparatus, which is proposed for use at a new semiconductor ion implantation facility. One part of the apparatus is used to slow down He ions which are positive and have a charge twice that of an electron (He^{++}). This part consists of a circular wire that is charged negatively so that it becomes a circle of charge. The ion has a velocity of 200 m/s when it passes through the center of the circle of charge on a trajectory perpendicular to the plane of the circle. The circle has a charge of 8.0 μC and radius of 3.0 cm. The sample with which the ion is to collide will be placed 2.5 mm from the charged circle. To check if this device will work, you decide to calculate the distance from the circle that the ion goes before it stops. To do this calculation, you assume that the

circle is very much larger than the distance the ion goes and that the sample is not in place. Will the ion reach the sample? You look up the charge of an electron and mass of the helium in your trusty Physics text to be 1.6×10^{-19} C and 6.7×10^{-27} Kg.

5. *Electric Force:* You've been hired to design the hardware for an ink jet printer. You know that these printers use a deflecting electrode to cause charged ink drops to form letters on a page. The basic mechanism is that uniform ink drops of about 30 microns radius are charged to varying amounts after being sprayed out towards the page at a speed of about 20 m/s. Along the way to the page, they pass into a region between two deflecting plates that are 1.6 cm long. The deflecting plates are 1.0 mm apart and charged to 1500 volts. You measure the distance from the edge of the plates to the paper and find that it is one-half inch. Assuming an uncharged droplet forms the bottom of the letter, how much charge is needed on the droplet to form the top of a letter 3 mm high (11 pt. type)?

6. *Electric Force:* While working in a University research laboratory your group is given the job of testing an electrostatic scale, which is used to precisely measure the weight of small objects. The device consists of two very light but strong strings attached to a support so that they hang straight down. An object is attached to the other end of each string. One of the objects has a very accurately known weight while the other object is the unknown. A power supply is slowly turned on to give each object an electric charge. This causes the objects to slowly move away from each other. When the power supply is kept at its operating value, the objects come to rest at the same horizontal level. At that time, each of the strings supporting them makes a different angle with the vertical and that angle is measured. To test your understanding of the device, you first calculate the weight of an unknown sphere from the measured angles and the weight of a known sphere. Your known is a standard sphere with a weight of 2.000 N supported by a string that makes an angle of 10.00° with the vertical. The unknown sphere's string makes an angle of 20.00° with the vertical. As a second step in your process of understanding this device, estimate the net charge on a sphere necessary for the observed deflection if a string were 10 cm long. Make sure to give the assumptions you used for this estimate.

7. *Electric Force:* You and a friend have been given the task of designing a display for the Physics building that will demonstrate the strength of the electric force. Your friend comes up with an idea that sounds neat theoretically, but you’re not sure it is practical. She suggests you use an electric force to hold a marble in place on a sloped plywood ramp. She would get the electric force by attaching a uniformly charged semicircular wire near the bottom of the ramp, laying the wire flat on the ramp with each of its ends pointing straight up the ramp. She claims that if the charges on the marble and ring and the slope of the ramp are chosen properly, the marble would be balanced midway between the ends of the wire.
   To test this idea, you decide to calculate the necessary amount of charge on the marble for a reasonable ramp angle of 15 degrees and a semicircle of radius 10 cm with a charge of 800 micro-coulombs. The marble would roll in a slot cut lengthwise into the center of the ramp. The mass of the lightest marble you can find is 25 grams.

8. *Electric Force, Gauss’s Law:* You have a great summer job in a research laboratory with a group investigating the possibility of producing power from fusion. The device being designed confines a hot gas of positively charged ions, called plasma, in a very long cylinder with a radius of 2.0 cm. The charge density of the plasma in the cylinder is 6.0×10^{-5} C/m^3. Positively charged Tritium ions are to be injected into the plasma perpendicular to the axis of the cylinder in a direction toward the center of the cylinder. Your job is to determine the speed that a Tritium ion should have when it enters the plasma cylinder so that its velocity is zero when it reaches the axis of the cylinder. Tritium is an isotope

of Hydrogen with one proton and two neutrons. You look up the charge of a proton and mass of the tritium in your trusty Physics text to be 1.6×10^{-19} C and 5.0×10^{-27} Kg.

9. *Electric and Gravitational Force:* You and a friend are reading a newspaper article about nuclear fusion energy generation in stars. The article describes the helium nucleus, made up of two protons and two neutrons, as very stable so it doesn't decay. You immediately realize that you don't understand why the helium nucleus is stable. You know that the proton has the same charge as the electron except that the proton charge is positive. Neutrons you know are neutral. Why, you ask your friend, don't the protons simply repel each other causing the helium nucleus to fly apart? Your friend says she knows why the helium nucleus does not just fly apart. The gravitational force keeps it together, she says. Her model is that the two neutrons sit in the center of the nucleus and gravitationally attract the two protons. Since the protons have the same charge, they are always as far apart as possible on opposite sides of the neutrons. What mass would the neutron have if this model of the helium nucleus works? Is that a reasonable mass? Looking in your physics book, you find that the mass of a neutron is about the same as the mass of a proton and that the diameter of a helium nucleus is 3.0×10^{-13} cm.

10. *Electric Field:* You are helping to design a new electron microscope to investigate the structure of the HIV virus. A new device to position the electron beam consists of a charged circle of conductor. This circle is divided into two half circles separated by a thin insulator so that half of the circle can be charged positively and half can be charged negatively. The electron beam will go through the center of the circle. To complete the design your job is to calculate the electric field in the center of the circle as a function of the amount of positive charge on the half circle, the amount of negative charge on the half circle, and the radius of the circle.

11. *Electric Field:* You have a summer job with the telephone company working in a group investigating the vulnerability of underground telephone lines to natural disasters. Your task is to write a computer program which will be used determine the possible harm to a telephone wire from the high electric fields caused by lightning. The underground telephone wire is supported in the center of a long, straight steel pipe that protects it. When lightening hits the ground it charges the steel pipe. You are concerned that the resulting electric field might harm the telephone wire. Since you know that the largest field on the wire will be where it leaves the end of the pipe, you calculate the electric field at that point as a function of the length of the pipe, the radius of the pipe, and the charge on the pipe.

Electric Potential Energy

12. *Electric Potential Energy:* While sitting in a restaurant with some friends, you notice that some "neon" signs are different in color than others. You know that these signs are essentially just gas sealed in a glass tube. The gas, when heated electrically, gives off light. One of your friends, who is an art major, and makes such signs as sculpture, tells you that the color of the light depends on which gas is in the tube. All "neon" signs are not made using neon gas. You know that the color of light tells you its energy. Red light is a lower energy than blue light. Since the light is given off by the atoms, which make up the gas, the different colors must depend on the structure of the different atoms of different gases. Suppose that atomic structure is as given by the Bohr theory which states that electrons are in uniform circular motion around a heavy, motionless nucleus in the center of the atom. This theory also states that the electrons are only allowed to have certain orbits. When an atom changes from one allowed orbit to another allowed orbit, it radiates light as required by the conservation of energy. Since only certain orbits are allowed, so the theory goes, only light of certain energies (colors) can be emitted. This seems to agree with the observations of your artist friend. You decide to test the theory by calculating the

energy of light emitted by a simple atom when an electron makes a transition from one allowed orbit to another. You decide to consider hydrogen since you know it is the simplest atom with one electron and a nucleus consisting of one proton. You remember that the proton has a mass 2000 times that of an electron. When you get home you look in your textbook and find the electron mass is 9×10^{-31} kg and its charge is 1.6×10^{-19} C. The radius of the smallest allowed electron orbit for hydrogen is 0.5×10^{-10} meters, which determines the normal size of the atom. The next allowed orbit has a radius 4 times as large as the smallest orbit.

13. *Electric Potential Energy:* You have a great summer job working in a cancer research laboratory. Your team is trying to construct a gas laser that will give off light of an energy that will pass through the skin but be absorbed by cancer tissue. You know that an atom emits a photon (light) when an electron goes from a higher energy orbit to a lower energy orbit. Only certain orbits are allowed in a particular atom. To begin the process, you calculate the energy of photons emitted by a Helium ion in which the electron changes from an orbit with a radius of 0.30 nanometers to another orbit with a radius of 0.20 nanometers. A nanometer is 10^{-9} m. The helium nucleus consists of two protons and two neutrons.

14. *Electric Potential Energy:* Your job is to evaluate an electron gun designed to initiate an electron beam. The electrons have a 20 cm path from the heating element, which emits them to the end of the gun. This path is through a very good vacuum. For most applications, the electrons must reach the end of the gun with a speed of at least 10^7 m/s. After leaving the heating element, the electrons pass through a 5.0 mm diameter hole in the center of a 3.0 cm diameter charged circular disk. The disk's charge density is kept at 3.0 μC/m^2. The heating element is a spherical electrode 0.10 mm in diameter that is kept at a very high charge of -0.10C. There is 1.0 cm between the heating element and the hole in the disk. Your first step is to determine if the electrons are going fast enough. Your boss has pointed that the hole in the disk is too large to ignore in your calculations. Using your physics text you find that the mass of the electron is 9.11×10^{-31} kg.

15. *Electric Potential Energy - Gauss's Law:* You have landed a summer job working with an Astrophysics group investigating the origin of high-energy particles in the galaxy. The group you are joining has just discovered a large spherical nebula with a radius 1.2 million km. The nebula consists of about 5×10^{10} hydrogen nuclei (protons) which appear to be uniformly distributed in the shape of a sphere. At the center of this sphere of positive charge is a very small neutron star. Your group had detected electrons emerging from the nebula. A friend of yours has a theory that the electrons are coming from the neutron star. To test that theory, she asks you to calculate the minimum speed that an electron would need to start from the neutron star and just make it to outside the nebula. From the inside cover of your trusty physics text you find that the charge of a proton (and an electron) is 1.6×10^{-19} C, the mass of the proton is 1.7×10^{-27} kg, and the mass of the electron is 9.1×10^{-31} kg.

16. *Electric Potential Energy, Gauss's Law:* You are working in cooperation with the Public Health department to design an electrostatic trap for particles from auto emissions. The average particle enters the device and is exposed to ultraviolet radiation that knocks off electrons so that it has a charge of $+3.0 \times 10^{-8}$ C. This average particle is then moving at a speed of 900 m/s and is 15 cm from a very long negatively charged wire with a linear charge density of -8.0×10^{-6} C/m. The detector for the particle is located 7.0 cm from the wire. In order to design the proper kind of detector, your colleagues need to know the speed that an average emission particle will have if it hits the detector. They tell you that an average emission particle has a mass of 6.0×10^{-9} kg.

17.. *Electric Potential Energy, Heat Energy (Heat Capacity, Latent Heat):* You are reading a newspaper report of a lightning strike in Jackson, Wyoming. Two men were sitting at a table outside a small cafe on a beautiful 30 ^{o}C day when a thunderstorm approached. Suddenly, a bolt of lightning struck a large aspen tree near their table. Needless to say, the men were very startled. One of the men remarked, "It just about scared the espresso out of me." They reported that when the bolt hit the tree and there was a loud hiss and a release of much steam from the tree. The lightning had boiled away some of the tree's sap. You are curious, and wonder how much water could be evaporated in this manner. So you study your physics book and make a few estimates and assumptions. You estimate that the electric potential difference between the tree and the thunderhead cloud was about 10^8 volts, and the amount of charge released by the bolt was about 50 Coulombs. You also assume that about 1% of the electrical energy was actually transferred into the sap, which is essentially water. The specific heat capacity of water is 4200 J/(kg ^oC) and its heat of vaporization is 2.3×10^6 J/kg.

18. *Electric Potential Energy, Gravitational Force:* NASA has asked your team of rocket scientists about the feasibility of a new satellite launcher that will save rocket fuel. NASA's idea is basically an electric slingshot that consists of 4 electrodes arranged in a horizontal square with sides of length d at a height h above the ground. The satellite is then placed on the ground aligned with the center of the square. A power supply will provide each of the four electrodes with a charge of +Q/4 and the satellite with a charge -Q. When the satellite is released from rest, it moves up and passes through the center of the square. At the instant it reaches the square's center, the power supply is turned off and the electrodes are grounded, giving them a zero electric charge. To test this idea, you decide to use energy considerations to calculate how big Q will have to be to get a 100 kg satellite to a sufficient orbit height. Assume that the satellite starts from 15 meters below the square of electrodes and that the sides of the square are each 5 meters. In your physics text you find the mass of the Earth to be 6.0×10^{24} kg.

19.. *Electric Potential Energy, Mechanical Energy:* You have been able to get a part-time job in a University laboratory. The group is planning a set of experiments to study the forces between nuclei in order to understand the energy output of the Sun. To do this experiment, you shoot alpha particles from a Van de Graaf accelerator at a sheet of lead. The alpha particle is the nucleus of a helium atom and is made of 2 protons and 2 neutrons. The lead nucleus is made of 82 protons and 125 neutrons. The mass of the neutron is almost the same as the mass of a proton. To assure that you are actually studying the effects of the nuclear force, an alpha particle should come into contact with a lead nucleus. Assume that both the alpha particle and the lead nucleus have the shape of a sphere. The alpha particle has a radius of 1.0×10^{-13} cm and the lead nucleus has a radius 4 times larger. Your boss wants you to make two calculations:
(a) What is the minimum speed of such an alpha particle if the lead nucleus is fixed at rest?
(b) What is the potential difference between the two ends of the Van de Graaf accelerator if the alpha particle starts from rest at one end (from a bottle of helium gas)?

Electric Power

20. It's a cool day, about 10 ^oC, so you plan to make about 5.0 kg of clear soup using your slow cooking crockpot. To decide whether the soup will be ready for dinner, you estimate how long it will take before the soup gets to its boiling point. Before adding the ingredients, you turn the crockpot over and read that it is a 200-ohm device that operates at 120 volts. Since your soup is mostly water, you assume it has the same thermal properties as water, so its specific heat capacity is 4200 J/(kg ^oC) and its heat of vaporization is 2.3×10^6 J/kg.

21. You are working with a company that has the contract to design a new, 700-foot high, 50-story office building in Minneapolis. Your boss suddenly bursts into your office. She has been talking with an

engineer who told her that when the elevator is operating at maximum speed, it would take the 6500-lb loaded elevator one minute to rise 20 stories. She thinks this is too long a time for these busy executives to spend in an elevator after returning from lunch at the Minneapolis Athletic Club. She wants you to buy a bigger power supply for the elevator. You look up the specifications for the new supply and find that it is the same as the old one except that it operates at twice the voltage. Your boss's assistant argues that the operating expenses of the new power supply will be much more than the old one. Your boss wants you to determine if this is correct. You estimate that while the elevator runs at maximum speed, the whole system, including the power supply, is 60% efficient. The cost of electricity is $0.06 per kilowatt-hour (commercial rate).

22. You have finally graduated from college and found a job with the Washington State Agricultural Concerns Group. Farmers and fishermen are concerned that the rate that water flows in the Columbia river, which is controlled by dams, will not be adequate for both irrigation needs and salmon spawning. The dams control the river's flow rate to produce most of the electrical power for cities along the West Coast. Your group leader assigns you the task of calculating the volume of water per second (flow rate) which normally would flow through the Grand Coulee Dam, the largest on the Columbia River. She tells you that this dam typically generates 2000 megawatts (MW) of power and is 50% efficient in converting the water's energy to electrical energy. The dam is 170 meters high ,and the water is kept in a lake 10 meters below the top of the dam. The Columbia River is 170 meters wide at the dam. The density of water is 1.00 g/cm^3.

Circuits

23. *Ohm's Law:* Because of your physics background, you landed a summer job as an assistant technician for a telephone company in California. During a recent earthquake, a 1.0-mile long underground telephone line is crushed at some point. This telephone line is made up of two parallel copper wires of the same diameter and same length, which are normally not connected. At the place where the line is crushed, the two wires make contact. Your boss wants you to find this place so that the wire can be dug up and fixed. You disconnect the line from the telephone system by disconnecting both wires of the line at both ends. You then go to one end of the line and connect one terminal of a 6.0-V battery to one wire, and the other terminal of the battery to one terminal of an ammeter (which has essentially zero resistance). When the other terminal of the ammeter is connected to the other wire, the ammeter shows that the current through the wire is 1 A. You then disconnect everything and travel to the other end of the telephone line, where you repeat the process and find a current of 1/3 A.

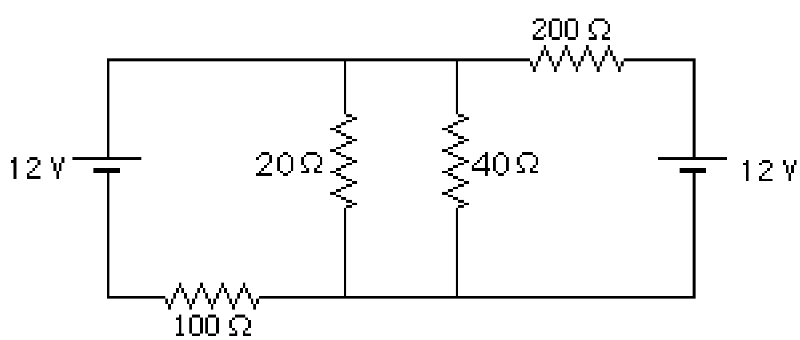
24. *Ohm's Law:* You have a summer job in the University ecology lab. Your supervisor asks you to duplicate an electromagnet that she has borrowed. She tells you that this electromagnet is made by wrapping a wire many times around a piece of iron and provides you with all the parts, the same type of wire of the same diameter and an identical iron core. What you need to know is how much wire to wrap around the iron. Unfortunately, you cannot simply unwrap the wire from the borrowed magnet because that will destroy it. On the side of the electromagnet, it tells you that when a potential difference of 12 V is put across the ends of its wire, there is a current of 0.06 A through the wire. With a brilliant flash of insight, you realize that the cross-sectional area and the conductivity is the same for both the magnet's wire and the wire you have, so you can find the length with a simple experiment. You cut off a 100-foot piece of identical wire from your supply, attach it to a 1.5-V flashlight battery and

measure a current of 0.10 A through that wire. Eureka! you can now find the length of the magnet's wire.

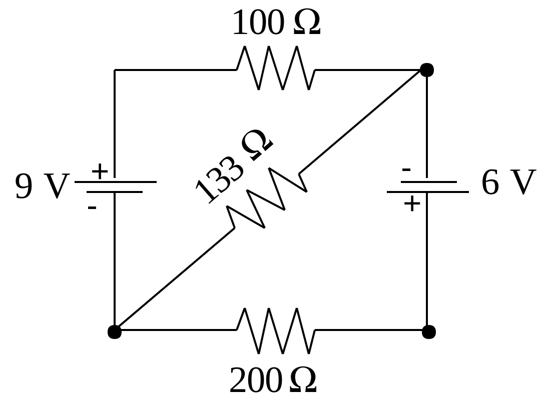
25 *Electric Power:* You and a friend are studying for an exam and the session goes until the early morning. At about 4 am you decide to cook some breakfast. Despite being sleepy you've got the coffee perking. Now you want to make some waffles but you realize there might be a problem. The 1000-watt waffle iron and the 600-watt coffee maker are plugged into the 110 V kitchen electrical outlets. If you plug in your 700-watt blender, will you overload the 20 A circuit breaker? The circuit breaker protects those kitchen circuit wires that have the most current from carrying too much current. You are trying to figure out how the electrical outlets are connected together in a circuit when your friend reminds you that when you disconnect the coffeepot, the waffle iron stays on. Now everything is clear.

26. *Electric Power:* You and a friend are studying for a final and the session goes until the early morning. About 4 AM you decide to cook some breakfast. Despite being sleepy, things are going well. The waffles are cooking and the coffee is perking. Should you make some toast now? The 1000-watt waffle iron and the 600-watt coffee maker are plugged into kitchen wall electrical outlets. You will also use a kitchen wall outlet for the toaster. The kitchen wall outlets are all part of the same 110-V circuit which has a 20-A circuit breaker (with negligible resistance) to protect the wire carrying the largest current from getting too hot. (Some homes have fuses to do the same job). You know that if you plug in too many appliances you will overload the circuit breaker. The toaster label says that its power output is 700 watts.

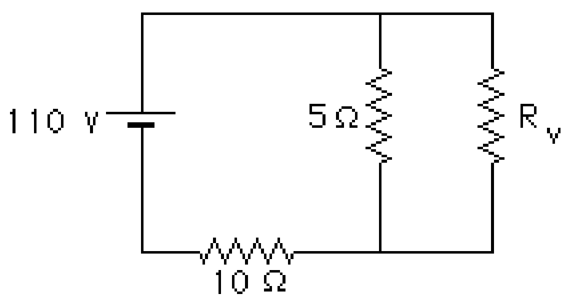
27. *Electric Power:* As a member of the safety group for the space shuttle scientific program, you have been asked to evaluate an electronics design change. In order to improve the reliability of a circuit to be used in the next shuttle flight, the experimental design team has suggested adding a second 12 V battery to the circuit. The equivalent resistances of the proposed design are shown below. You are worried about the heat generated by the device with the 20 ohm resistance since it will be located next to a sensitive low temperature experiment so you do the appropriate calculation.



28. *Electric Power:* As part of your summer job as a design engineer at an electronics company, you have been asked to inspect the circuit shown below. The resistors are rated at 0.5 Watts, which means they burn-up if more than 0.5 Watts of power passes through them. Will the 100Ω resistor in the circuit burn-up?



29. *Electric Power:* While trying to find the power ratings of your appliances you find their circuit diagrams. Looking them over, your friend believes there must be a typo in the circuit diagram of your toaster. The heating element that toasts the bread is listed as having a resistance of 5 ohms. A variable resistor, which is changed by a knob on front of the toaster, has a range of from 2 to 20 ohms. Your friend feels that an element with this resistance will not toast bread properly. Based on the circuit diagram, given below, you decide to calculate the maximum power output by the heating element.



$R_{v\ min} = 2\ \Omega$

$R_{v\ max} = 20\ \Omega$

Magnetic Force and Field

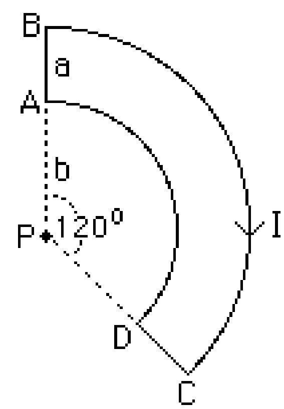
30. *Magnetic Force:* You are working on a project to make a more efficient engine. Your team is investigating the possibility of making electrically controlled valves that open and close the input and exhaust openings for an internal combustion engine. Your assignment is to determine the stability of the valve by calculating the force on each of its sides and the net force on the valve. The valve is made of a thin but strong rectangular piece of non-magnetic material that has a loop of current carrying wire along its edges. The rectangle is 0.35 cm x 1.83 cm. The valve is placed in a uniform magnetic field of 0.15 T such that the field lies in the plane of the valve and is parallel to the short sides of the rectangle. The region with the magnetic field is slightly larger than the valve. When a switch is closed, a 1.7 A current enters the short side of the rectangle on one side of the valve and leaves on the opposite side. To give different currents through the wires along the long sides of the valve, a resistor is inserted into the wire on each of these sides. The value of the resistor on one side is twice that on the other side.

31. *Magnetic Force:* You have landed a great summer job in the medical school assisting in a research group investigating short lived radioactive isotopes which might be useful in fighting cancer. Your group is working on a way of transporting alpha particles (Helium nuclei) from where they are made to another room where they will collide with other material to form the isotopes. Since the radioactive isotopes are

not expected to live very long, it is important to know precisely how much time it will take to transport the alpha particles. Your job is to design that part of the transport system which will deflect the beam of alpha particles ($m = 6.64 \times 10^{-27}$ kg, $q = 3.2 \times 10^{-19}$ C) through an angle of 90^o by using a magnetic field. The beam will be traveling horizontally in an evacuated tube. At the place the tube is to make a 90^o turn you decide to put a dipole magnet which provides a uniform vertical magnetic field of 0.030 T. Your design has a tube of the appropriate shape between the poles of the magnet. Before you submit your design for consideration, you must determine how long the alpha particles will spend in the uniform magnetic field in order to make the 90^o-turn.

32. *Magnetic Force:* You've just learned about the earth's magnetic field and how a compass works and you are relaxing in front of the TV. Tired of your show, you think about how the picture tube works in relation to what you have learned. In a typical color picture tube for a TV, the electrons are boiled off of a cathode at the back of the tube and are accelerated through about 20,000 volts towards the picture tube screen. On the screen is a grid of ``color dots'' about 1/100 inch apart. When the electrons hit them, the dots scintillate their appropriate colors producing the color picture. Without taking apart the set, you determine whether the manufacturer needed to shield the color picture tube from the earth's magnetic field?

33. *Magnetic Field (Biot-Savart Law):* You are continually having troubles with the CRT screen of your computer and wonder if it is due to magnetic fields from the power lines running in your building. A blueprint of the building shows that the nearest power line is as shown below. Your CRT screen is located at point P. Calculate the magnetic field at P as a function of the current I and the distances a and b. Segments BC and AD are arcs of concentric circles. Segments AB and DC are straight-line segments.



34. *Magnetic Field - Ampere's Law:* While studying intensely for your physics final you decide to take a break and listen to your stereo. As you unwind, your thoughts drift to newspaper stories about the dangers of household magnetic fields on the body. You examine your stereo wires and find that most of them are coaxial cable, a thin conducting wire at the center surrounded by an insulator, which is in turn surrounded by a conducting shell. The inner wire and the conducting shell are both part of the circuit with the same current (I) passing through both, but in opposite directions. As a way to practice for your physics final you decide to calculate the magnetic field in the insulator, and outside the coaxial cable as a function of the current and the distance from the center of the cable. As an additional challenge to yourself, you calculate what the magnetic field would be (as a function of the current and the distance from the center of the cable) inside the outer conducting shell of the coaxial cable. For this you assume that the inner radius of the conducting shell is R_1 and the outer radius is R_2.

35. *Magnetic Force - Faraday's Law:* You have a summer job working at a company developing systems to safely lower large loads down ramps. Your team is investigating a magnetic system by modeling it in the laboratory. The safety system is a conducting bar that slides on two parallel conducting rails that run down the ramp. The bar is perpendicular to the rails and is in contact with them. At the bottom of the ramp, the two rails are connected together. The bar slides down the rails through a vertical uniform magnetic field. The magnetic field is supposed to cause the bar to slide down the ramp at a constant velocity even when friction between the bar and the rails is negligible. Before setting up the laboratory model, your task is to calculate the constant velocity of the bar sliding down the ramp on rails in a vertical magnetic field as a function of the mass of the bar, the strength of the magnetic field, the angle of the ramp from the horizontal, the length of the bar which is the same as the distance between the tracks, and the resistance of the bar. Assume that all of the other conductors in the system have a much smaller resistance than the bar.