Context-rich Problems in This Section

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. An example from the final examination is shown on the next page.
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.

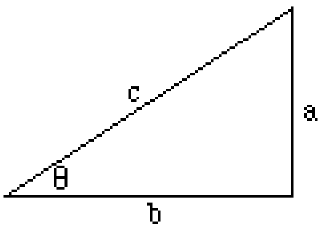
The context-rich problems in this section are grouped according to the fundamental concepts and principle(s) required for a solution:

Notes:

Equations: Two-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: $A = 4\pi R^2$, $V = \frac{4}{3}\pi R^3$

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

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

Fundamental Concepts and Principles:

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

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

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

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

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

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

Under Certain Conditions:

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

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

$$\Delta E_{internal} = cm\Delta T\qquad \Delta E_{internal} = mL\qquad \vec{F} = -G\frac{m_1 m_2}{r^2}\hat{r}\qquad U = -G\frac{m_1 m_2}{r}\qquad \vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{E} = k\frac{q}{r^2}\hat{r}\qquad U = k_e\frac{q_1 q_2}{r}\qquad \Delta V = \frac{\Delta U}{q}\qquad R = \rho\frac{L}{A}\qquad \Delta V = IR$$

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

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, $R_E = 4\text{x}10^3$ miles, $G = 6.7\text{x}10^{-11}\ Nm^2/kg^2$, $k_e = 9.0 \times 10^9\ Nm^2/C^2$, $e = 1.6 \times 10^{-19}$ C,

$\mu_o = 4p$ x 10^{-7} T m/A

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 ($1\ \text{ft}/(10^{-9}\ \text{sec})$).
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?