2D Motion Problems

(modified from http://groups.physics.umn.edu/physed/Research/CRP/on-lineArchive/crlk.html#1dcv)

Projectile Launched Horizontally

23. 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.

24. 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.

25. 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.

26. 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.

27. 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.

Projectile Launched at an Angle

28. 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 86º from the vertical at 100 feet from the archer.

29. 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?

30. 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?

31. 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 30º 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.

32. 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 30o. How much time did the fielder have to react to the hit, run to the fence, and leap up to make the catch ?

33. 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?

34. 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.

35. 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.

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. 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.

37. 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 10º 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.

38. 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 0.40 g 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 30º from the vertical. Can this probe work as designed?

39. 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.

40. 40. 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 x 106 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.

41. 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.

42. 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?