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.

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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 x 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 x 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?