

Physics 8, Fall 2023, Exam Problems.

Study and solve these problems, most of which closely resemble worksheet problems you've solved in class. Keep working until you are confident in your ability to solve each problem without looking at written solutions (your own, mine, or someone else's). Feel free to discuss the problems with your classmates — just bear in mind that your goal should be to develop your own understanding, not simply to copy down an answer. You're also welcome to check with Bill or Marija to see whether your approach to a given problem is sound.

The real exam will be completed in person, at a chalkboard or whiteboard, in groups of 2 or 3 students. (If you prefer to present your solutions on your own, in a group of 1, we can arrange that, but I think you will be more comfortable with the camaraderie of a fellow student or two.)

We will solve the same problems at the board, with no notes, no books, no computers, no electronic gadgets, but if you need help remembering an equation or some other detail, you can ask me and your fellow students for help. We will also cooperate to make sure we agree on each part of a problem before going on to the next part. If arithmetic is needed, I'll use my computer to work out numbers for expressions you write on the board.

We will take turns (choosing at random) leading the discussion of the problems (selected in random order), with one person at the board at a time, but I and your fellow students can offer input if you like. For a longer problem, one person will lead for part (a), then another person will lead for part (b), and so on. For a short problem, one person can lead while the rest of us help to avoid mistakes.

Marija will be in the back of the room to take notes. Each person will be graded individually, based on your demonstrating to us that you know how to solve the problems and understand the physics behind each problem. The exam is not a huge part of your grade, just 25%, and many of you have accumulated worksheet and reading scores above 100%. There is also my standard option to earn up to a maximum of 5% extra-credit via supplementary readings or a variety of computer exercises that some students in past years have completed. So this is not a high-stakes exam. My hope is that this format, while unusual, will provide more learning and less stress than a traditional written final exam, and I hope it will be a good fit for the cooperative problem-solving format we have used throughout the semester. The same format worked out well with the fall 2021 students.

We will stop when we've finished all of the problems, or when two hours have elapsed, whichever comes first. Working slowly while showing good understanding is a valid approach, so you don't need to feel pressure to work quickly.

Groups are determined by who signs up for which time slots (maximum of 3 people per time slot), which may or may not coincide with your usual workgroups. I already circulated via email the link to the online signup spreadsheet. We will meet either in my office (DRL 1W15) or in a nearby DRL classroom.

Solutions for most of these problems, with some details edited, are among the collection of old exams and solutions at positron.hep.upenn.edu/p8/files/oldexams. But do try each problem yourself before looking to see how I solved it! Really the best way to check your work while practicing is to solve the problems **independently** and **then** to compare notes with 2 or 3 classmates to compare methods and results.

Problem 1. You have been hired to check the technical correctness of an upcoming made-for-TV murder mystery. The mystery takes place in the International Space Station. In one scene, an astronaut's safety line is sabotaged while she is on a space walk, so she is no longer connected to the space station. She checks and finds that her thruster pack has also been damaged and no longer works. She is 100 meters from the station and moving with it. That is, she is not moving with respect to the station. There she is drifting in space with only a few minutes of air remaining. To get back to the shuttle, she decides to unstrap her 10.0 kg tool kit and throw it away with all her strength, so that the toolkit has a speed of 10.0 m/s. According to the script, she makes it back to the shuttle before running out of air. Her mass, including space suit (but without the tool kit) is 100.0 kg.

(a) In what direction should the astronaut throw her tool kit?

(b) After the astronaut throws away her tool kit, what is her velocity (with respect to the space station)?

(c) How long does it take her to reach the space station? What do you conclude about whether the murder-mystery script (story) is plausible?

Problem 2. A woman applies a constant force to pull a 10.0 kg box across a floor. The force is large enough to cause the box to accelerate horizontally forward (toward the woman) at 1.00 m/s^2 . The woman applies this force by pulling on a rope that makes an angle of 36.9° above the horizontal, and for the box-floor interface, the coefficient of kinetic friction is $\mu_k = 0.200$.

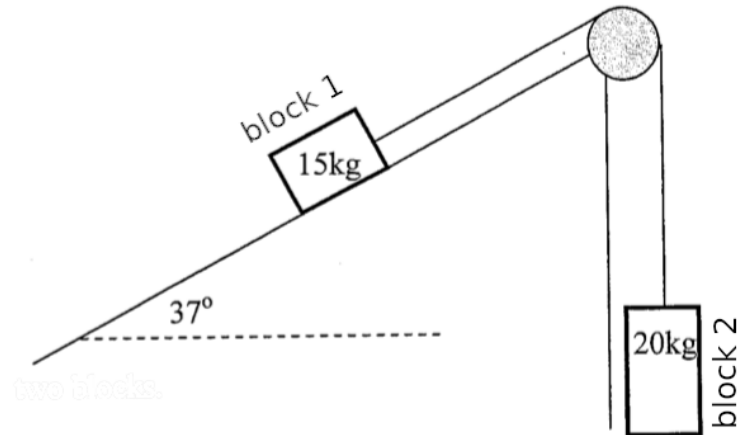
(a) Draw a Mazur-style free-body diagram (FBD, not EFBD) for the box. Show all forces acting on the box and separately indicate the acceleration of the box.

(b) Find the tension in the rope.

(c) Label your FBD with numerical values for all of the forces that you indicated on your diagram.

(d) How far does the box travel in 2.0 seconds?

Problem 3. A block of mass $m_1 = 15\text{ kg}$ slides on an inclined plane that makes an angle $\theta = 37^\circ$ above the horizontal. A taut cable passes from this block over a massless and frictionless pulley to a second block of mass $m_2 = 20\text{ kg}$, which is suspended from the same cord. When the system is released from rest, block 1 moves up along the inclined plane with an uphill acceleration $a_x = 2.0\text{ m/s}^2$. (Since the cable stays taut, block 2 moves directly down with this same acceleration.) There is friction between block 1 and the inclined plane (with coefficient μ that you will determine below), but block 2 is not in contact with any surface. Use the same coordinate x to represent both the uphill motion of block 1 and the downward motion of block 2.



(a) Draw a Mazur-style free-body diagram (FBD, not EFBD) for block 1, and draw a Mazur-style FBD for block 2. Be sure to indicate, adjacent to each FBD, the direction of acceleration for the corresponding block.

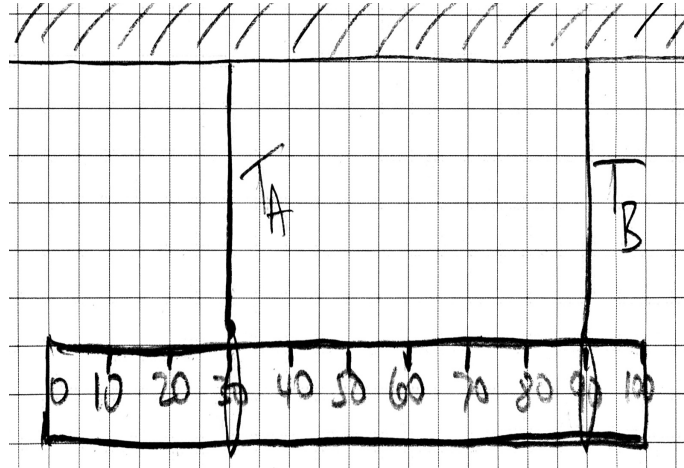
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(b) Write Newton's second law, $ma_x = \sum F_x$, separately for each of the blocks. Since the cable stays taut, a_x is the same for both blocks. (But the x -axis points uphill for block 1 and points straight downward for block 2.)

(c) What is the tension T in the cord?

(d) Determine the coefficient of kinetic friction, μ_K , between the first block and the inclined plane. (It is the one remaining unknown, so you can solve for it.)

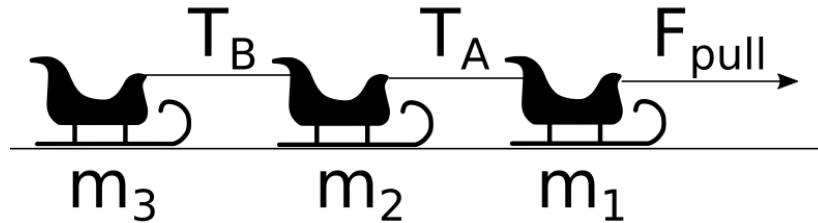
Problem 4. A meter stick of mass 1.00 kg is supported, in a horizontal orientation, by two vertical strings, one at the 30 cm mark and the other at the 90 cm mark.



(a) What is the tension (T_B) in the string at 90 cm? (I mean the tension in the straight part of the string that is above the ruler; don't worry about the small portion that encircles the ruler.)

(b) What is the tension (T_A) in the string at 30 cm?

Problem 5. Three sleds are pulled to the right across a horizontal sheet of ice using horizontal cables. Friction between the ice and the sleds is negligible. The three sleds (numbered from right to left) have masses $m_1 = 10.0$ kg, $m_2 = 20.0$ kg, and $m_3 = 10.0$ kg respectively. The pull exerted by the tow cable on sled 1 is $F_{\text{pull}} = 60$ N to the right. Sleds 1 and 2 are connected by a taut cable of tension T_A . Sleds 2 and 3 are connected by a taut cable of tension T_B .



(a) Find the acceleration a_x of the three-sled system, where the x axis points to the right.

(b) Find the tensions T_A and T_B . I found it easier to find T_B first, then T_A .

(Problem continues on next page.)

(c) Draw a free-body diagram for sled 3, then a free-body diagram for sled 2, then a free-body diagram for sled 1. Include both horizontal and vertical forces. Indicate the numerical magnitude of every force (including proper units).

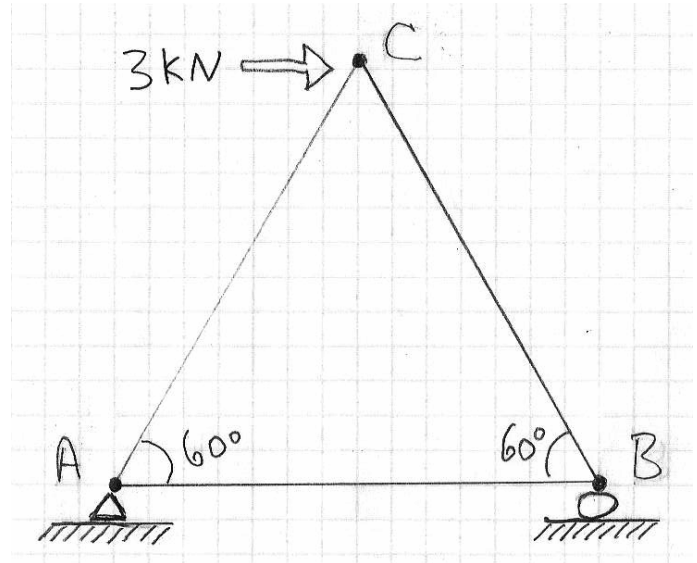
(d) How far does the 3-sled system travel in 2.0 seconds, starting from rest?

Problem 6. Two male reindeer charge head-on at each other with the same speed and meet on an icy patch of tundra. The larger reindeer is charging to the right, and the smaller reindeer is charging to the left. As they collide, their antlers lock together and the two animals slide together with one-third of their original speed.

(a) What is the ratio of their masses?

(b) In which direction do they slide after colliding?

7. (a) Use the Method of Joints to find the internal bar forces T_{AB} , T_{AC} , and T_{CB} in the truss shown below. You can work in any order you wish, but what worked out quickly for me was to start with the vertical forces at C , then horizontal forces at C , then horizontal forces at B . Be sure to indicate whether each bar is in tension or in compression.

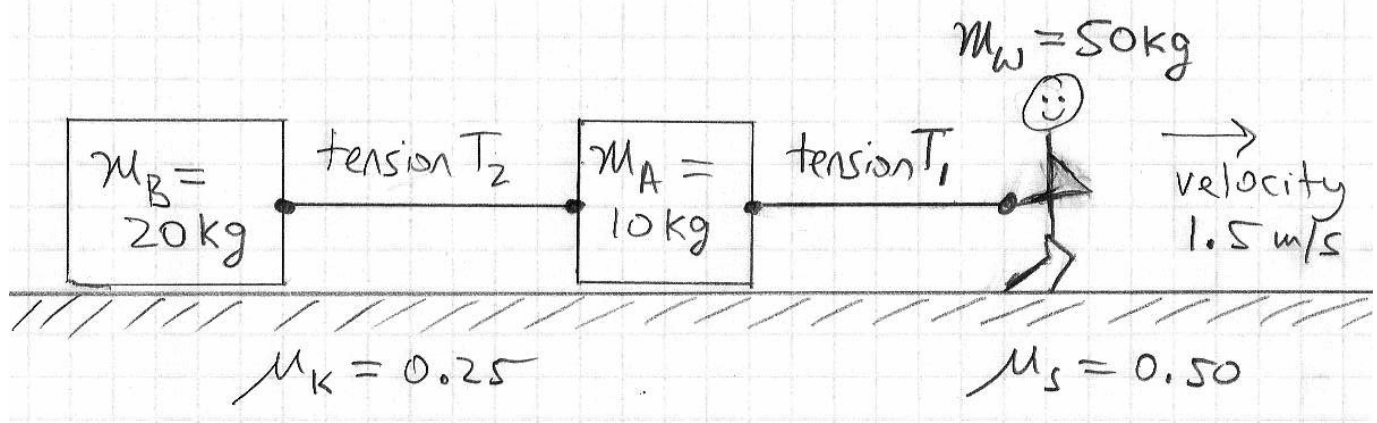


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(b) Find the support forces A_x , A_y , and B_y exerted on the truss by the pin support at A and by the roller support at B . Be sure to indicate whether each of these forces points up, down, left, or right. The easiest way to get B_y is to continue to use the Method Of Joints to write the vertical forces at B . After that, it's straightforward to find A_x and A_y .

(c) As a double-check on your answer for B_y , evaluate the moment (torque) equation, for equilibrium of the truss as a whole, using joint A as a pivot. Take the distance from A to B to be L , so then the height of the triangle is $0.866L = L \sin(60^\circ)$.

8. A worker chooses an unusual way to pull two boxes across a factory floor. The worker pulls one tow rope, which she has tied to the front of Box A . A second tow rope connects the back of Box A to the front of Box B . Both ropes are taut, horizontal, and of negligible mass; the floor is horizontal; and the worker and both boxes move to the right at constant velocity $v = 1.5 \text{ m/s}$. The boxes slide across the floor, but the worker's shoes do not slip as she walks. The coefficient of static friction between the worker's shoes and the floor is $\mu_s = 0.50$, while the coefficient of kinetic friction between each box and the floor is $\mu_k = 0.25$.



(a) List all forces (in all directions, both horizontal and vertical) **acting on** Box B . For each force, indicate what kind of force it is, indicate “by what” and “on what” the force is exerted, and note the force’s magnitude and direction.

(b) Draw a Mazur-style free-body diagram (FBD, not EFBD) for Box B .

(Problem continues on next page.)

(c) List all forces (in all directions, both horizontal and vertical) **acting on** Box *A*. For each force, indicate what kind of force it is, indicate “by what” and “on what” the force is exerted, and note the force’s magnitude and direction.

(d) Draw a Mazur-style free-body diagram (FBD, not EFBD) for Box *A*.

(e) List all forces (in all directions, both horizontal and vertical) **acting on** the worker. For each force, indicate what kind of force it is, indicate “by what” and “on what” the force is exerted, and note the force’s magnitude and direction.

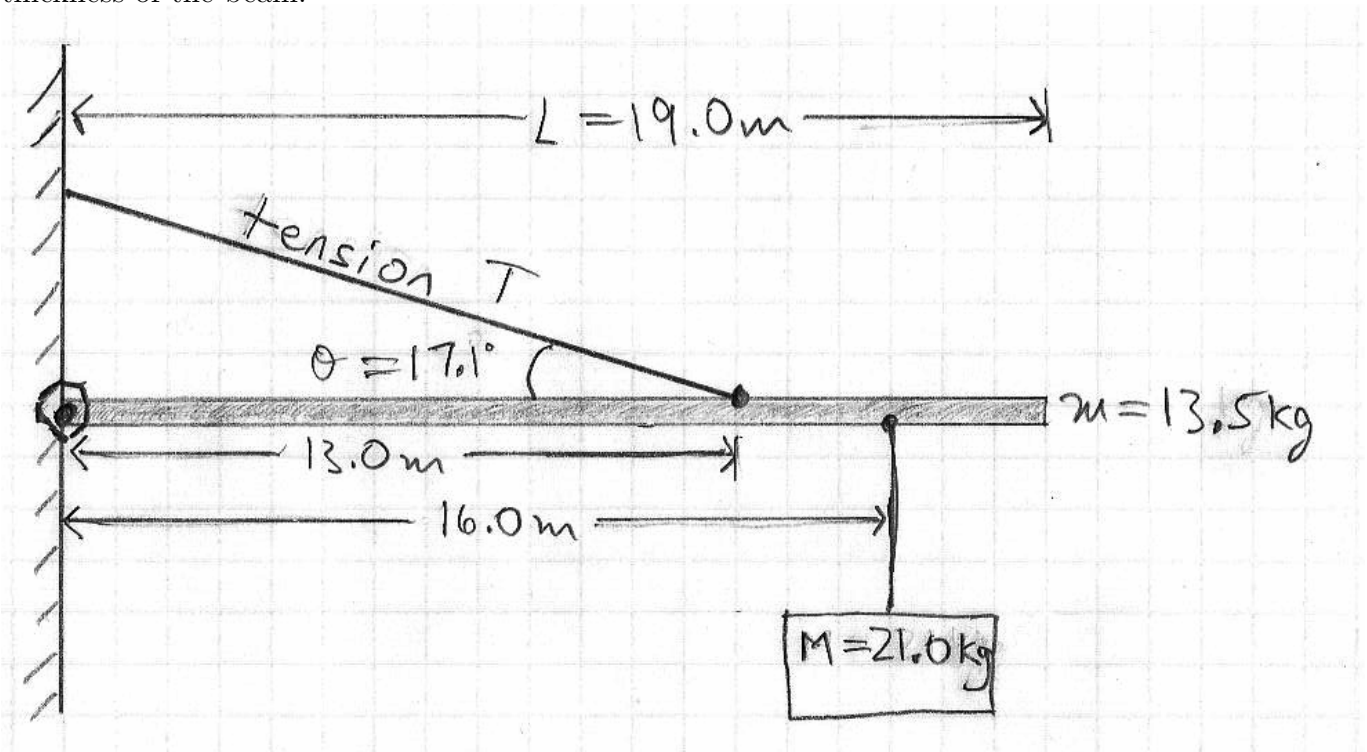
(f) Draw a Mazur-style free-body diagram (FBD, not EFBD) for the worker.

(Problem continues on next page.)

(g) What are the tensions T_2 and T_1 in the two tow ropes?

(h) Suppose that all of the details of this problem stay unchanged, but the boxes are made more massive. (The worker's mass is unchanged, and the friction coefficients are unchanged.) What is the largest combined mass, $m_A + m_B$, for the two boxes that the worker could pull, at constant velocity, before her shoes begin to lose their grip on the floor?

9. A shop sign of mass $M = 21.0\text{ kg}$ is suspended from a uniform beam of mass $m = 13.5\text{ kg}$ and length $L = 19.0\text{ m}$. The horizontal beam is supported on the left by a hinge; the beam is also supported, a distance 13.0 m from the hinge, by a guy wire that makes an angle $\theta = 17.1^\circ$ w.r.t. the beam. The sign is supported 16.0 m from the hinge. Neglect the mass of the guy wire and the thickness of the beam.



(a) Draw an extended free-body diagram for the beam, indicating all forces acting on the beam, their directions, and their lines of action. Don't forget the mass of the beam itself.

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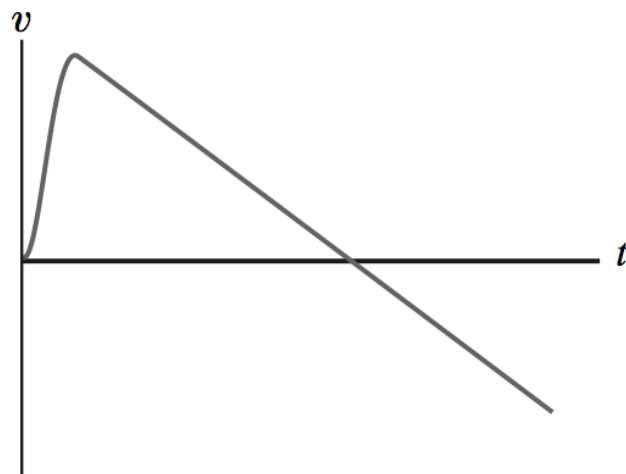
(b) Find the tension T in the diagonal guy wire and the forces F_x and F_y exerted by the hinge on the beam. (Remember that forces are in newtons, while masses are in kilograms.)

(c) If the guy wire has a circular cross-section of radius $R = 0.0100$ m (that's 1.00 cm), what is the (tensile) stress in the guy wire? (Remember that stress has units of N/m^2 .)

(d) If the guy wire is made of steel having Young's modulus $E = 2.0 \times 10^{11}$ N/m^2 and has unstretched length 13.6 m, by how much does the guy wire stretch (i.e. how much does its length increase) when it is under tension?

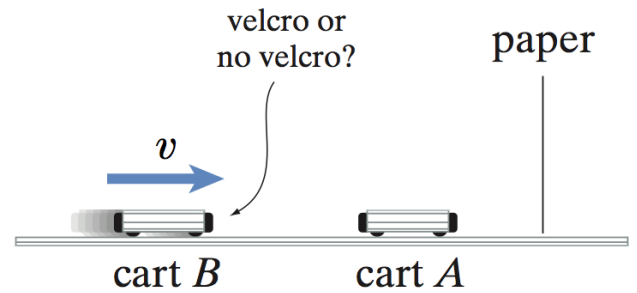
10. The graph at right shows the velocity vs. time curve for the first part of the motion of an object traveling along a line. Which of the motion(s) described below could be represented by the graph?

- A) a person sprinting 100 m from rest
- B) a ball thrown in the air
- C) a ball kicked at a wall from which it rebounds
- D) a ball, released from rest, rolling down a uniform slope
- E) a bus journey from one stop to the next
- F) none of the above



Briefly explain your reasoning.

11. You want to drive cart **A**, initially at rest, through a piece of paper by launching cart **B** against it. Both carts have the same mass, and you've determined that the larger the kinetic energy of an object, the more easily it goes through a piece of paper. One side of cart **B** is equipped with velcro pads so that it sticks to cart **A**; the other side is smooth and collides elastically. Which side of cart **B** do you use? Explain briefly.

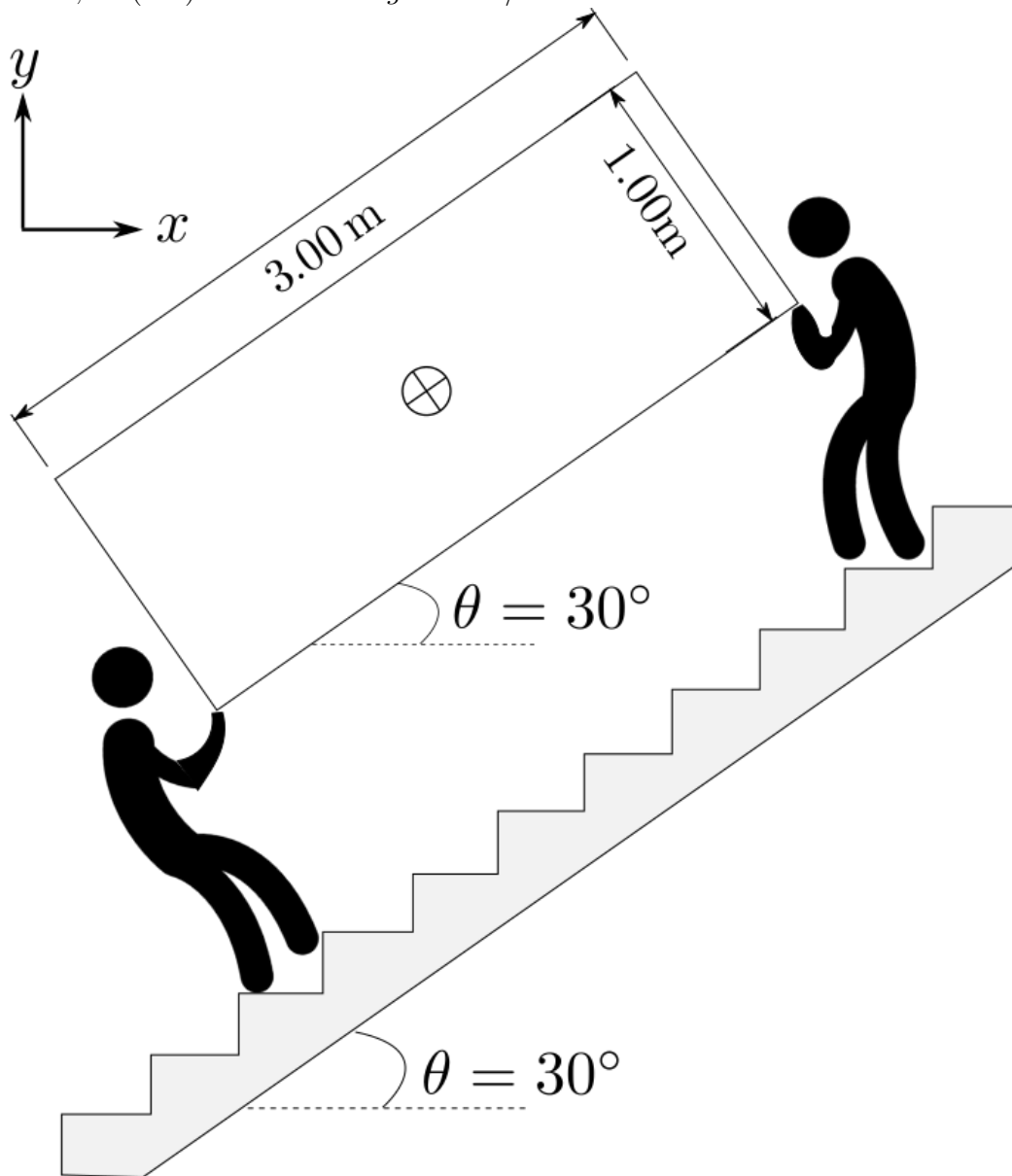


12. While driving cross-country over holiday break, you become bored with the music you are playing and decide to change CDs. Alas, your CD case is sitting on the far-right side of the passenger seat, beyond the reach of your right arm. You decide to use your knowledge of physics to slide the CD case closer to you — so you'll make a sharp turn. Conveniently, just ahead on the highway are one exit ramp turning right and another exit ramp turning left.

(a) Which direction should you turn the car so as to make the CD case slide closer to you?

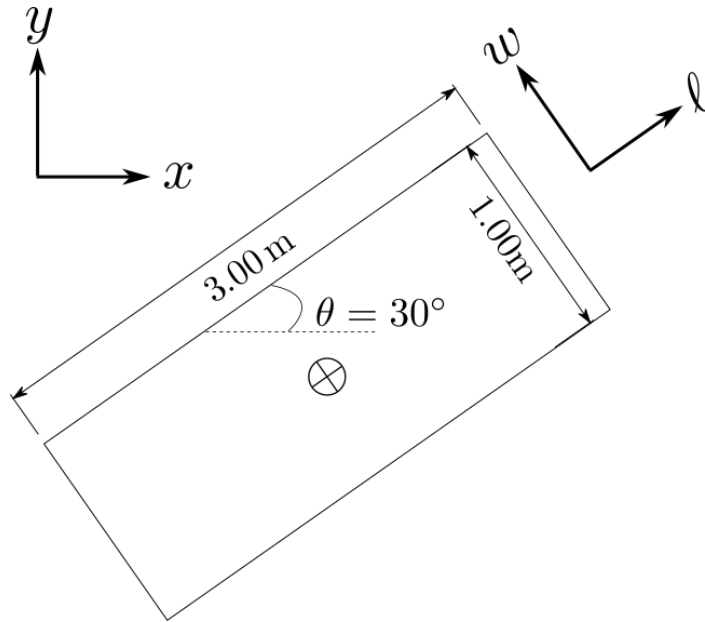
(b) If the coefficient of static friction between the CD case and the seat of the car is 0.40, and the exit ramp is circular with a radius of 50 m, what is the minimum constant speed at which you could make your turn and still have the CD case slide your way?

13. You and your friend are paused for a moment while you are in the middle of carrying a 100 kg box up a flight of stairs. The box is 3.00 m long and 1.00 m wide (high), and the contents of the box are somehow arranged so that the center of gravity is at the center of the box, as indicated. The stairs make a 30.0° angle to the floor. The box is carried at a 30.0° angle, so that the box's long side is parallel to the staircase. Assume that each person applies, with her hands, a **purely vertical force** to the corresponding corner of the box. In other words, the person below applies a force only in the $+y$ direction at the corner that she touches, and the person above applies a force only in the $+y$ direction at the corner that she touches, with the y axis as indicated. In case it helps: $\cos(30^\circ) \approx 0.866$, $\sin(30^\circ) = 0.500$. Use $g \approx 10 \text{ m/s}^2$.



(Problem continues on next page.)

(a) Turn the figure below into an Extended Free Body Diagram by drawing onto the diagram, with correct lines of action, the force F_A exerted on the box by the person above on the staircase, the force F_B exerted on the box by the person below on the staircase, and the force F^G exerted on the box by Earth's gravity. All of these forces should point along the $\pm y$ axis. Then **decompose** F^G into components along the w and ℓ axes, which are parallel to the width and length of the box. Be sure that the components of your decomposed F^G have the correct lines of action.



(b) Determine the magnitudes (give numbers, in newtons) of the forces F^G , F_A , and F_B . You should find that it is easier to be person A (above) than to be person B (below).

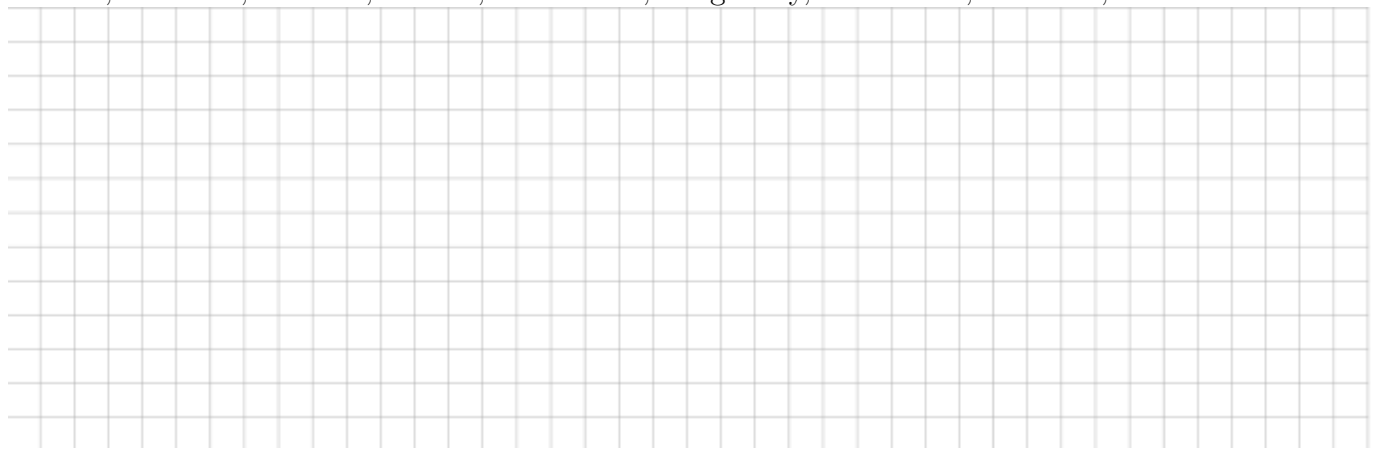
14. Conceptual force questions.

(a) When you stand still on the floor, how large a force does the floor exert on you? Why doesn't this force make you rise up into the air? Include with your answer a Mazur-style free-body diagram (FBD, not EFBD) for yourself, indicating the forces exerted on you as you stand still on the floor.

(Problem continues on next page.)

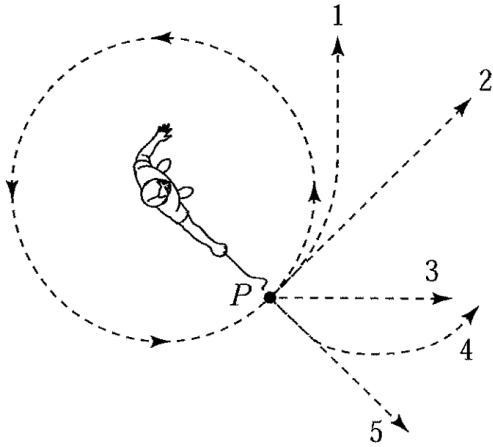
(b) A worker pushes boxes in a factory. In each case decide which force has the greater magnitude: the force exerted by the worker on the box or the force exerted by the box on the worker. (i) The box is heavy and does not move no matter how hard she pushes. (ii) Some contents are removed, and now when pushed the box slides across the floor at constant speed. (iii) The worker pushes harder, and the box accelerates.

(c) You and a box are both at rest on a factory floor. You push (horizontally) on the box, and the box starts to slide but you remain at rest. Draw a Mazur-style free-body diagram for you and one for the box. Include all relevant forces, both vertical and horizontal. Make it clear from the lengths of your arrows which forces have equal magnitudes. Then use the diagrams and your understanding of forces to explain why the box accelerates but you don't. You might want to label your forces with B=box, E=earth, F=floor, M=me, C=contact, G=gravity, N=normal, S=static, K=kinetic.



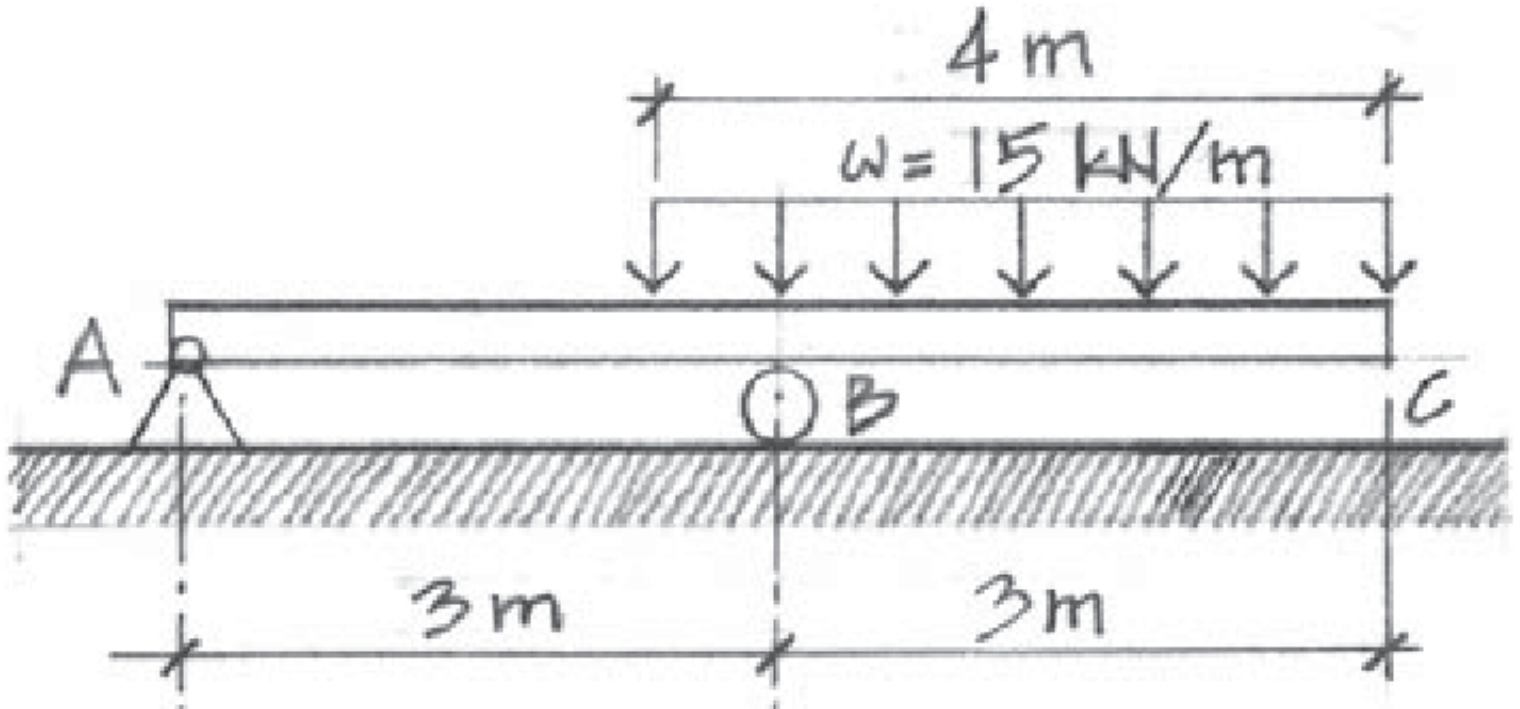
(d) You are in a stationary elevator, so that the contact force exerted by the elevator's floor on you is equal in magnitude to the force of gravity acting on you. When the elevator accelerates downward (and you accelerate downward with the elevator), which force changes? What happens to its magnitude?

(e) A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the figure below. At point P , the string suddenly breaks near the ball. If these events are observed from directly above, which of the 1–5 paths below would the ball most closely follow after the string breaks?

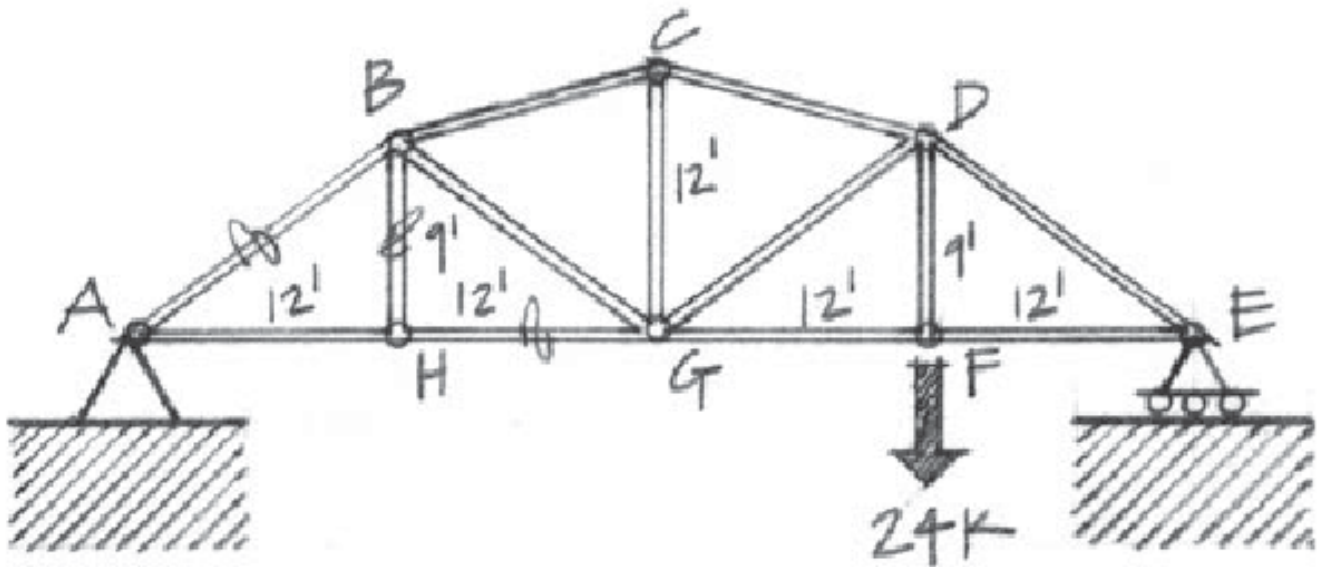


(f) A heavy crate rests on the bed of a flatbed truck. When the truck accelerates, the crate remains where it is on the truck, so it too accelerates. What force causes the crate to accelerate? Draw a Mazur-style free-body diagram for the crate. Be sure to indicate the direction of acceleration.

15. Solve for the support “reaction” forces at A and B (i.e. the forces exerted by the supports at A and B on the beam) in the figure below. To do this, you will need to convert the distributed load into an equivalent concentrated load. Remember that a hinge/pin support exerts two force components on the beam (though one component may equal zero eg if the loads are all vertical), while a roller support exerts one force component (in the normal direction). The first step in your solution should be a redrawn EFB diagram showing “reaction” forces and the concentrated load that is equivalent (for the purpose of calculating reaction forces) to the distributed load.



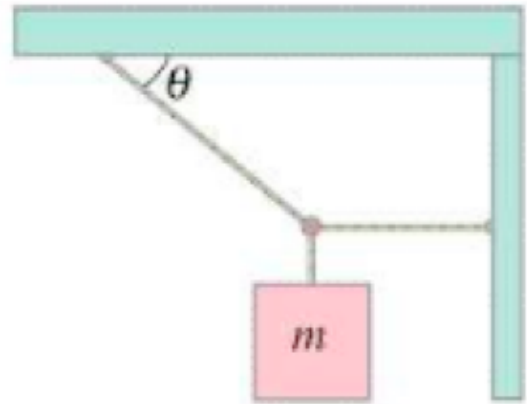
16. Using the method of sections, solve for the forces in bars AB , BH , and HG in the truss shown below. You'll need to start by solving for at least a subset of the support ("reaction") forces. (Hint: a well-chosen torque equation lets you directly solve for the support force at E.) Then draw and label an EFBD of the side of the truss that you do not erase. Indicate whether each of these bars is in tension or in compression. Use only one section cut through the truss. The truss is marked with distances in feet (!) and loads in "kips" (kilopounds). You can leave it as is, if you like, or you can pretend the markings are in meters and kilonewtons. Either way, use the given numbers; don't do any unit conversions. [If you draw this problem on the exam, we'll divide it into parts (I see 5 or 6 distinct values to solve for) and take turns.]



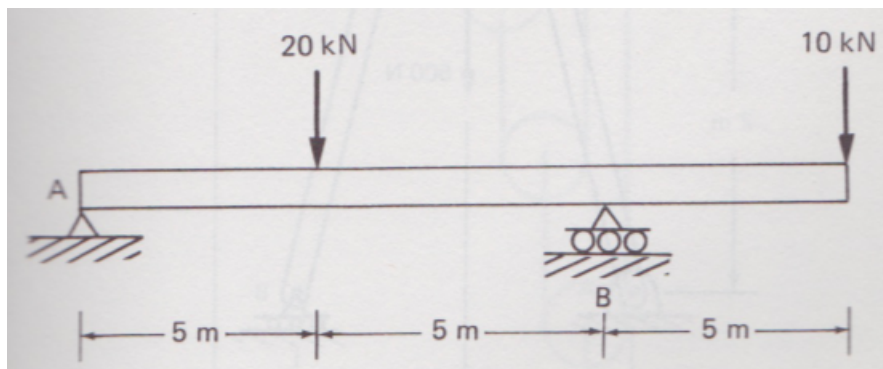
17. When a mass of 25 kg is suspended from the middle of a fixed straight aluminum wire (which is initially horizontal), the wire sags to make an angle of 2.0° with the horizontal, as shown below. (a) What is the tension in each of two diagonal wire segments? (b) If the original length of each wire segment was 1.000 m when it was horizontal (before the 25 kg mass was attached), what is its length when it is diagonal? (c) What is the strain in the wire? (d) If Young's modulus for aluminum is $7.0 \times 10^{10} \text{ N/m}^2$, what is the stress in the diagonal wire segments? (e) If the wire has a circular cross-section, what is the wire radius? (You know the tension (force) and you know the tensile stress, so you can calculate the area, and hence the radius.) [If you draw this problem on the exam, we'll take turns working part-by-part, and I'll use my computer to work out any arithmetic that you write down.]



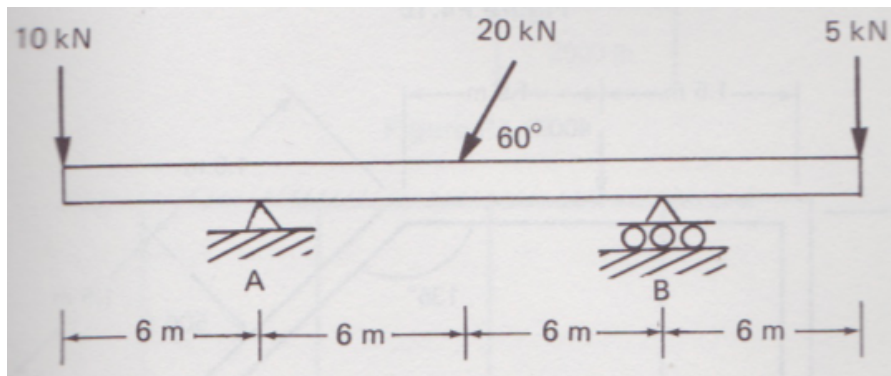
18. Find the tension in the two cords shown in the figure below (left). Neglect the mass of the cords, and assume that the angle θ is 30° and the mass m is 50 kg.



19. Using the equations for static equilibrium, find the “reaction” forces exerted by the supports on the beam in the left figure below. (There are three forces: two vertical and one horizontal. You may find that one force equals zero.)

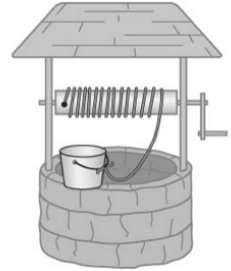


20. Find the “reaction” forces exerted by the supports **A** and **B** on the beam in the right figure above. (There are three forces to find: two vertical and one horizontal.)



21. A 10 kg ladder of length 10.0 m leans against a smooth wall and makes an angle of 53.1° with the ground. A 100 kg person starts to climb the ladder. (a) Draw an EFB_D for the ladder, when the person has climbed about one-quarter of the way up the ladder. (b) If the coefficient of static friction between the ground and the ladder is 0.40, what distance along the ladder can he or she climb before the ladder starts to slip?

22. You accidentally knock a full bucket of water off the side of the well shown in the figure. The bucket plunges 10 m to the bottom of the well. Attached to the bucket is a light rope that is wrapped around the crank cylinder. (a) How fast is the handle turning (rotational speed ω) when the bucket hits bottom? (b) How fast is the bucket moving (linear speed v) when it hits the bottom? The mass of the bucket plus water is 10 kg. The crank cylinder is a solid cylinder of radius 0.50 m and mass 4.0 kg. (Assume the small handle's mass is negligible in comparison with the crank cylinder.)



23. The coefficient of static friction of tires on ice is about 0.10. (a) What is the steepest driveway on which you could park under those circumstances? (b) Draw a free-body diagram for the car when it is parked (successfully) on an icy driveway that is just a tiny bit less steep than this maximum steepness. (You might want to do (b) before you do (a).)

24. A 1.0 kg block on a (very long!) horizontal tabletop is pushed against the free end of a spring (whose other end is attached to a wall) until the spring is compressed 0.50 m from its relaxed length. The spring constant is $k = 100$ N/m, and the coefficient of kinetic friction between block and tabletop is 0.20. When the block is released from being held against the compressed spring, how far does the block travel before coming to rest?