- Sit whereever you like! No worksheet today. Pick up a printed copy of the exam problems, so that you can discuss them with your classmates or with Melina and Bill.
- `positron.hep.upenn.edu/p8/files/exam2021.pdf`
- We'll do exam problems in random order, and we'll almost certainly run out of time before we run out of problems. I decided to include about $2\times$ as many problems as will fit in 2 hours, but my solutions for same or nearly identical problems are online at `positron.hep.upenn.edu/p8/files/oldexams` .
- Before Wednesday's class, watch ($2\times$ speed recommended) my 170-minute-long (!) "beams 2" video, covering O/K ch8.
- Prof Farley will visit our classroom via Zoom on Wednesday! We can send him questions `rfarley@design.upenn.edu` .
- Weds: we'll work a couple of example beam-design problems, just to give you a sense of how beam criteria are used. I'll also bring back several hands-on activities, in case you want more time with them.
- Last day to submit late work to Melina is Dec 15. Last day to submit XC to Bill is Dec 22.

1. Hands-on activity! Materials: 1.3 meter ringstand with protruding screwdriver for pivot. Wooden meter stick with holes drilled at 25 cm intervals. Ordinary wooden meter stick. Plastic meter stick. Wooden two-meter stick. Set of masses up to 1 kg. Tabletop vise. Several binder clips.

As you go along, quickly jot down just enough to convince Melina that you tried and understood most parts of the exercise. But the main goal is to have fun engaging hands-on with the physics. Feel free to go off-piste a bit and be creative! (If you do, briefly describe what you did, or call Bill or Melina over to see.)

(a) Using the ringstand to pivot the meter stick about its 50 cm hole, position one binder clip at each end of the meter stick such that you can get two 200 g masses to balance, one suspended from each end. (This establishes your setup.)

(b) Pick several other combinations of masses (eg 200 and 500 g, or 500 g and 1 kg) and when you get them to balance, verify that the positions where they balance are consistent with your understanding of torque. Jot down what masses you used and where they balanced.

(c) Try using the hole at 25 cm to convince yourself that the mass of the wooden meter stick is approximately 150 grams. Jot down an EFBD for the scenario you set up, illustrating why this works (eg where the line of action is for the gravitational force exerted by Earth on the meter stick). You can make 150 g by daisy-chaining 100 g and 50 g, or you can find your own cleverer solution.

(d) Try gently flexing the plastic meter stick and the ordinary wooden meter stick, to assess their stiffness. Since the two cross-sections are similar (though not identical, unfortunately), which material seems to have the larger Young's modulus? Try this comparison in both the "on the flat" (like a plank) and the "on edge" (like a joist) orientations. Which orientation has the larger "second moment of area" (aka "area moment of inertia)? In which orientation is the "beam" stiffer? A useful result that you will not see until O/K ch8 and the corresponding upcoming video is that the radius of curvature R (which is infinity for a straight line and gets smaller as the beam becomes more tightly curved) is given by $R = EI/M$ where E is Young's modulus, $I = \int y^2 \mathrm{d}A$ is the second moment of area, and M is the "bending moment," ie the internal torque within each section cut through the beam — which is proportional to the torque that you are applying with your two hands to the beam.

(e) Set up a cantilever using a wooden meter stick, either on end or on the flat. Your fellow student and the tabletop vise may both be helpful for holding the fixed end onto the table. Use a binder clip to attach a single concentrated load to the end of your cantilever, and watch the beam deflect under load. (Start with 200 g and go up if appropriate.) We'll see in O/K ch8 and the corresponding video that when you put a concentrated load P (for "point-like" force, as engineers write) at the far end of a cantilever of length L, the vertical deflection of the far end of the beam is $PL^3/(3EI)$, where E is Young's modulus and I is second moment of area.

(f) Try a couple of values of the load P to verify (roughly) that the deflection is proportional to the mass you place at the end.

(g) For a given load, try the same meter stick both "on edge" and "on the flat" to see the effect of the I factor. The aspect ratio of these wooden meter sticks' cross-section is about 3.2, whose square is approximately 10. Thus I is about $10\times$ larger "on edge" vs "on the flat." Thus, the deflection, for a given load, should be about $10\times$ as large "on the flat" as it is "on edge." Try this! You can do it side-by-side if you use two wooden meter sticks of the same cross-section and keep the lengths the same.

(h) Compare the wooden meter stick side-by-side with the plastic meter stick (cross-sections are similar, but unfortunately not identical), to see the effect of the E factor, Young's modulus.

(i) Use the long two-meter stick at a couple of different lengths (eg 0.5 m vs 1.0 m overhang) to see the effect of the L^3 factor. If you double the length of a cantilever with a point-load at its end, you multiply the deflection $\times 8$.

(j) Though we are mostly skipping the topic of vibration this semester, one important result we may have time to see very briefly is that for many systems, the natural frequency of oscillation is proportional to $\sqrt{(\text{stiffness})/(\text{inertia})}$. The stiffness of the wooden meter stick "on edge" is about $10\times$ as large as "on the flat," but the inertia of the two configurations is identical. Try plucking a wooden cantilever in each of the two configurations and see if you can hear that the natural frequency (or pitch) "on edge" is about $3\times$ as high as the natural frequency "on the flat." (When you increase pitch $\times 3$, you go up to the next octave, then go up another fifth, since an octave is $\times 2$ and a fifth is $\times 1.5$)

(k) As you increase the length of the cantilever the stiffness decreases much faster than the inertia increases, so the natural frequency goes down as you make your cantilever longer. Try this! (By the way, the end of a uniformly-loaded cantilever (eg under its own weight), has deflection $wL^4/(48EI)$, ie proportional to L^4.)

Physics 8, Fall 2021, 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 Dr Bill or Melina 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.

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.

Each person will be graded individually, based on your demonstrating to me 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

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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 will be 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. Available times (with a few exceptions when I have conflicts) will be 9–11am, 12–2pm, or 3–5pm every weekday from Dec 9 to Dec 22. I can probably also do Saturday afternoons if needed. 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!

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 $1.00\,\mathrm{m/s^2}$. 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 $\mu_k = 0.200$.

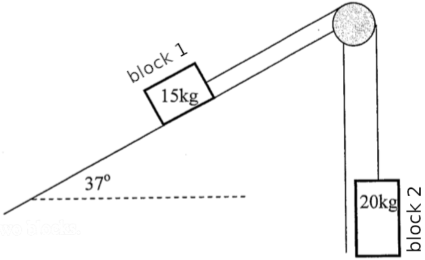
(a) Draw a Mazur-style free-body diagram (FBD, not EFBD) for the box. Show all forces acting on the box and separately indicate the acceleration of the box.

(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 $\theta = 37°$ 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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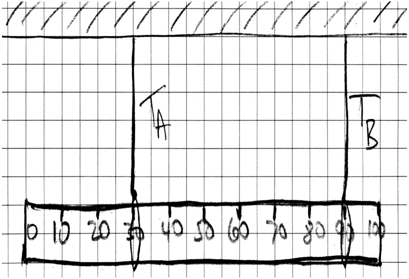
(Problem continues on next page.)

(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.)

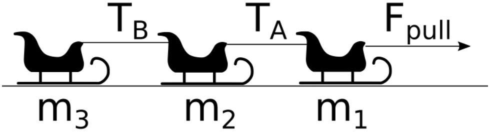
Problem 4. A meter stick of mass 1.00 kg is supported, in a horizontal orientation, by two vertical strings, one at the 30 cm mark and the other at the 90 cm mark.



(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 $30\,\mathrm{cm}$?

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 $m_1 = 10.0\,\text{kg}$, $m_2 = 20.0\,\text{kg}$, and $m_3 = 10.0\,\text{kg}$ respectively. The pull exerted by the tow cable on sled 1 is $F_{\text{pull}} = 60\,\text{N}$ 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?

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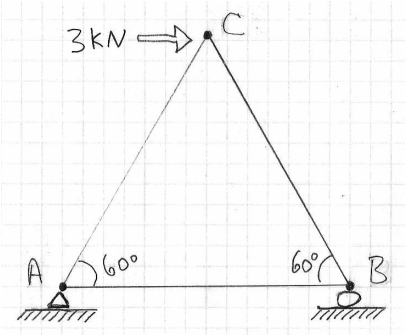
Problem 6. Two male reindeer charge head-on at each other with the same speed and meet on an icy patch of tundra. The larger reindeer is charging to the right, and the smaller reindeer is charging to the left. As they collide, their antlers lock together and the two animals slide together with one-third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



(Problem continues on next page.)

(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 $0.866L = (L/2)\tan(60°)$.

(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 $0.866L = (L/2)\tan(60°)$.

(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.

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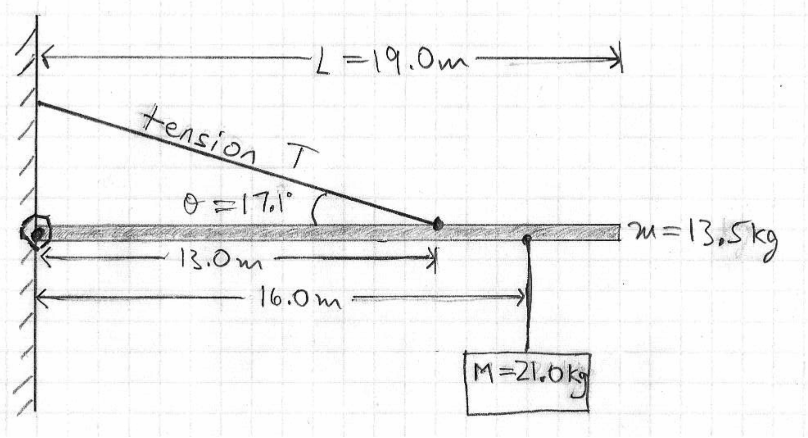
(f) Draw a Mazur-style free-body diagram (FBD, not EFBD) for the worker.

(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 $\theta = 17.1°$ 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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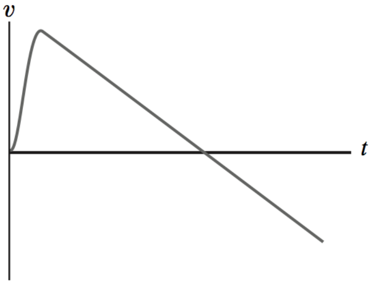
(Problem continues on next page.)

(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 $R = 0.0100\,\mathrm{m}$ (that's $1.00\,\mathrm{cm}$), what is the (tensile) stress in the guy wire? (Remember that stress has units of $\mathrm{N/m^2}$.)

(d) If the guy wire is made of steel having Young's modulus $E = 2.0 \times 10^{11}\,\mathrm{N/m^2}$ 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

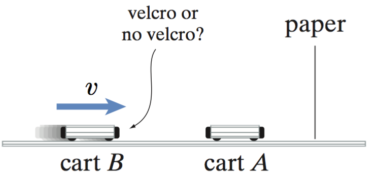
D) a ball, released from rest, rolling down a uniform slope

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?

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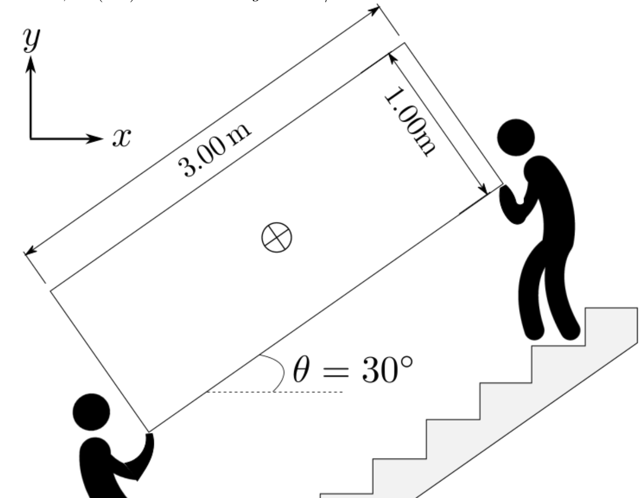
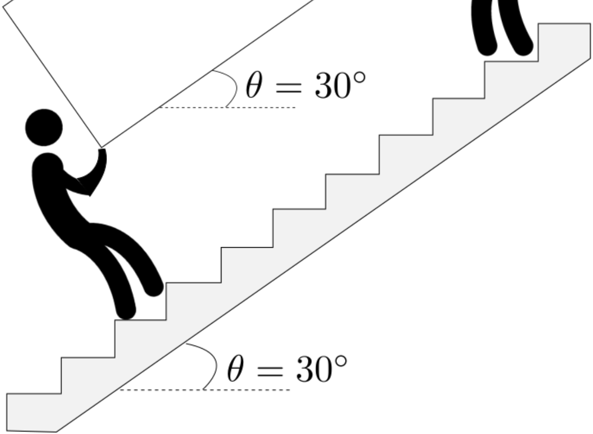
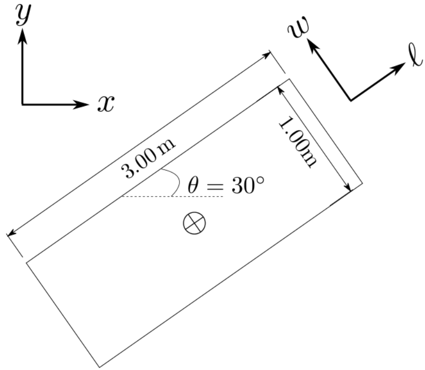
13. You and your friend are paused for a moment while you are in the middle of carrying a 100 kg box up a flight of stairs. The box is 3.00 m long and 1.00 m wide (high), and the contents of the box are somehow arranged so that the center of gravity is at the center of the box, as indicated. The stairs 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: $\cos(30°) \approx 0.866$, $\sin(30°) = 0.500$. Use $g \approx 10\,\mathrm{m/s^2}$.





(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.

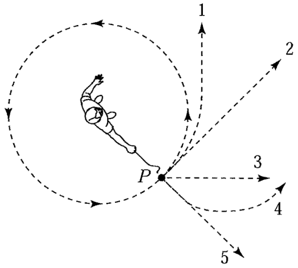
(Problem continues on next page.)

(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.