4 Forces and Newton's Laws of Motion

4.1 What Causes Motion?

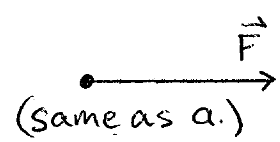
4.2 Force

1. Using the particle model, represent the force a person exerts on a table when (a) pulling it to the right across a level floor with a force of magnitude F, (b) pulling it to the left across a level floor with force $2F$, and (c) *pushing* it to the right across a level floor with force F.

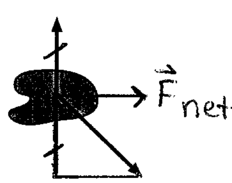
a. Table pulled right with force F

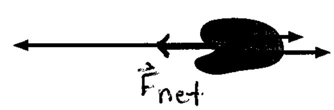
b. Table pulled left with force $2F$

c. Table pushed right with force F

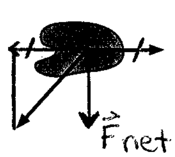


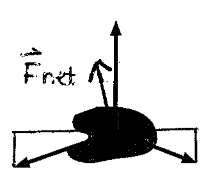
2. Two or more forces are shown on the objects below. Draw and label the net force $\vec{F}_{net}$.





3. Two or more forces are shown on the objects below. Draw and label the net force $\vec{F}_{net}$.





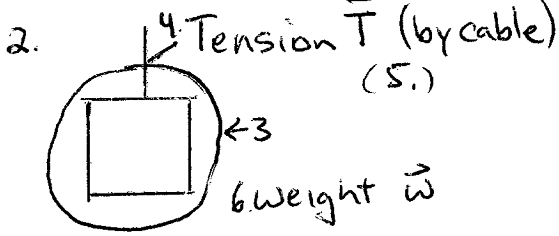
4.3 A Short Catalog of Forces

4.4 Identifying Forces

Exercises 4–8: Follow the six-step procedure of Tactics Box 4.2 to identify and name all the forces acting on the object.

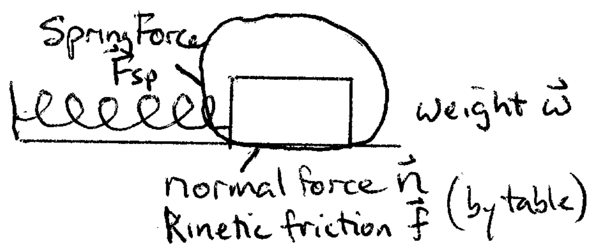
4. An elevator suspended by a cable is descending at constant velocity.

1. System: Elevator
Environment: Cable



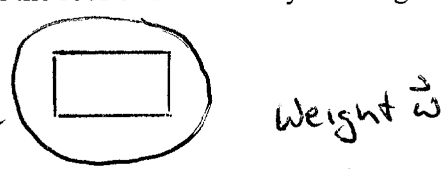
5. A compressed spring is pushing a block across a rough horizontal table.

System: Block
Environment: Spring, table



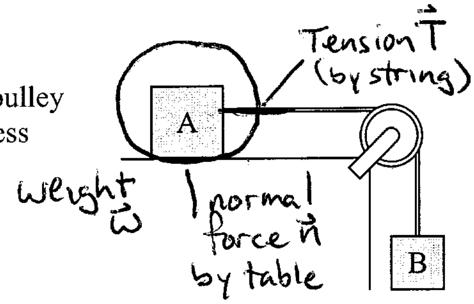
6 A brick is falling from the roof of a three-story building.

System: Brick
Environment: None



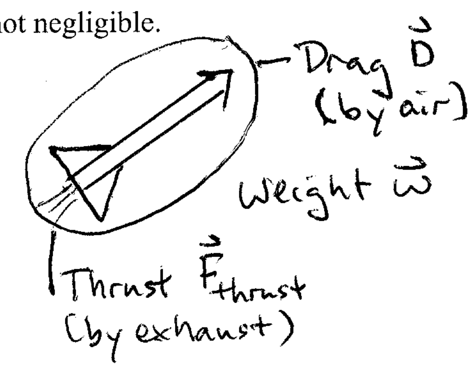
7. Blocks A and B are connected by a string passing over a pulley Block B is falling and dragging block A across a frictionless table. Let block A be "the system" for analysis.

System: Block A
Environment: String, table



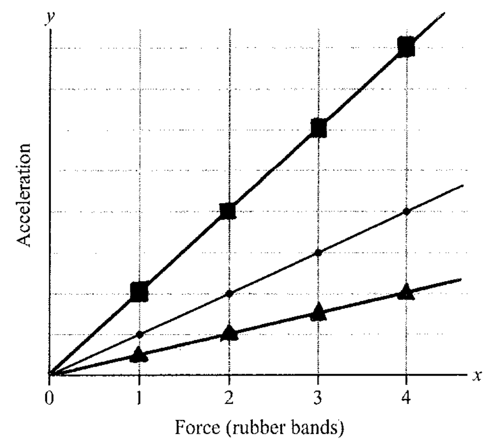
8. A rocket is launched at a 30° angle. Air resistance is not negligible.

System: Rocket
Environment: Air, exhaust



4.5 What Do Forces Do?

9. The figure shows an acceleration-versus-force graph for an object of mass m. Data have been plotted as individual points, and a line has been drawn through the points.



Draw and label, directly on the figure, the acceleration-versus-force graphs for objects of mass

a. $2m$ b. $0.5m$

Use triangles ▲ to show four points for the object of mass $2m$, then draw a line through the points. Use squares ■ for the object of mass $0.5m$.

10. A constant force applied to an object causes the object to accelerate at 10 m/s^2. What will the acceleration of this object be if

a. The force is doubled? $20\frac{m}{s^2}\left(=\frac{2F}{m}\right)$ b. The mass is doubled? $5\frac{m}{s^2}\left(=\frac{F}{2m}\right)$

c. The force is doubled *and* the mass is doubled? same, $10\frac{m}{s^2}\left(=\frac{2F}{2m}\right)$

d. The force is doubled *and* the mass is halved? $40\frac{m}{s^2}\left(=\frac{2F}{m/2}\right)$

11. A constant force applied to an object causes the object to accelerate at 8 m/s^2. What will the acceleration of this object be if

a. The force is halved? $4\frac{m}{s^2}$ b. The mass is halved? $16\frac{m}{s^2}\left(=\frac{F}{m/2}\right)$

c. The force is halved *and* the mass is halved? $8\frac{m}{s^2}\left(=\frac{F/2}{m/2}\right)$

d. The force is halved *and* the mass is doubled? $2\frac{m}{s^2}\left(=\frac{F/2}{2m}\right)$

12. The quantity y is inversely proportional to x and $y = 4$ when $x = 9$.

a. Write an equation to represent this inverse relationship for all y and x.

$y=\frac{a}{x}$ $4=\frac{a}{9}$ $a=4\times 9=36$ $y=\frac{36}{x}$

b. Find y if $x = 12$ $y=3$ c. Find x if $y = 36$ $x=1$

d. Compare your equation in part a to the equation from your text relating a and m, $a = \frac{F}{m}$.

Which quantity assumes the role of x? m

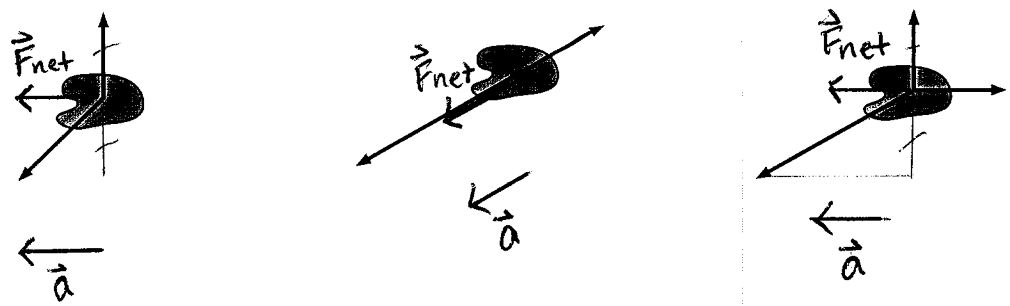
Which quantity assumes the role of y? a

What is the constant of proportionality relating a and m?

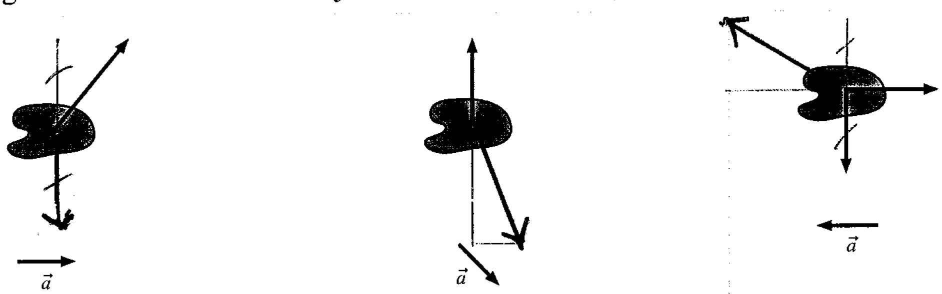
F

4.6 Newton's Second Law

13. Forces are shown on three objects. For each:
    a. Draw and label the net force vector. Do this right on the figure.
    b. Below the figure, draw and label the object's acceleration vector.

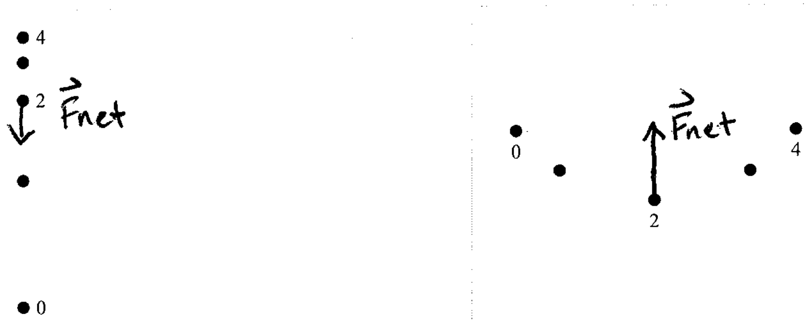


14. In the figures below, one force is missing. Use the given direction of acceleration to determine the missing force and draw it on the object. Do all work directly on the figure.



15. Below are two motion diagrams for a particle. Draw and label the net force vector at point 2.

16. Below are two motion diagrams for a particle. Draw and label the net force vector at point 2.



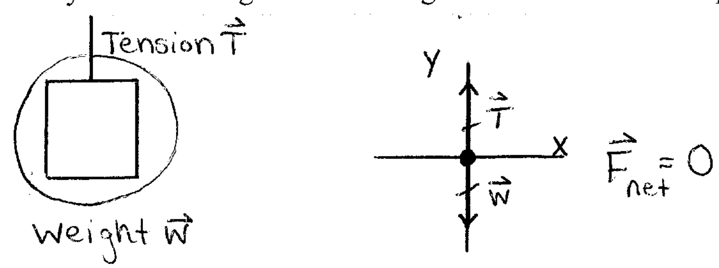
4.7 Free-Body Diagrams

Exercises 17–22:

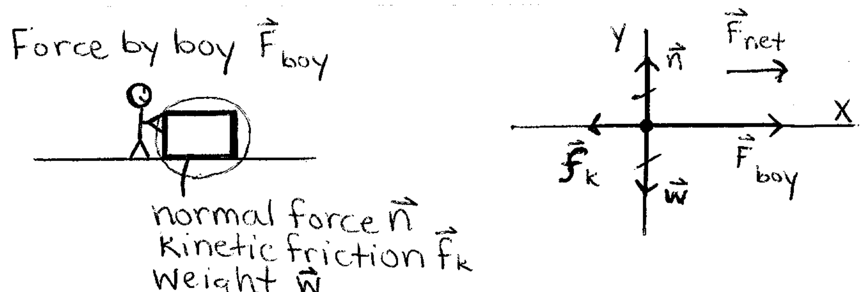
- Draw a picture and identify the forces, then
- Draw a complete free-body diagram for the object, following each of the steps given in Tactics Box 4.3. Be sure to think carefully about the direction of $\vec{F}_{net}$.

Note: Draw individual force vectors with a **black** or **blue** pencil or pen. Draw the *net* force vector $\vec{F}_{net}$ with a **red** pencil or pen.

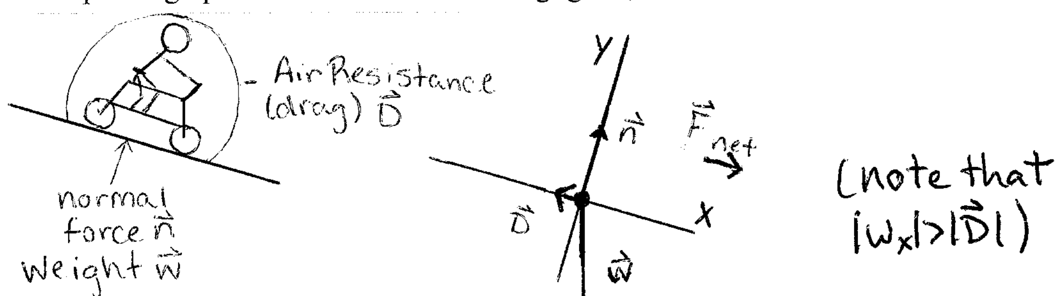
17. A heavy crate is being lowered straight down at a constant speed by a steel cable.



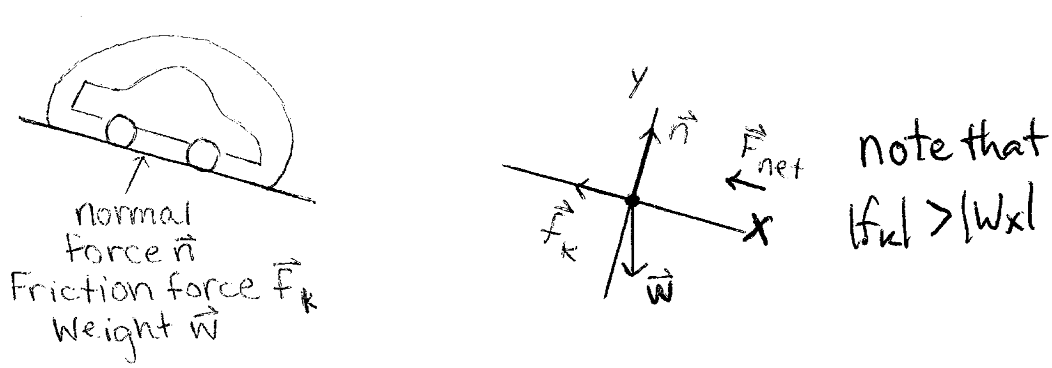
18. A boy is pushing a box across the floor at a steadily increasing speed. Let the box be "the system" for analysis.



19. A bicycle is speeding up down a hill. Friction is negligible, but air resistance is not.

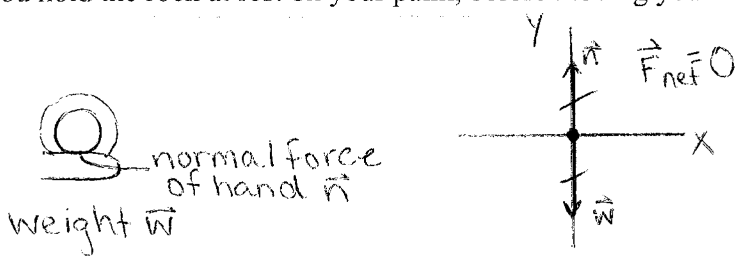


20. You've slammed on your car brakes while going down a hill. You're skidding to a halt.

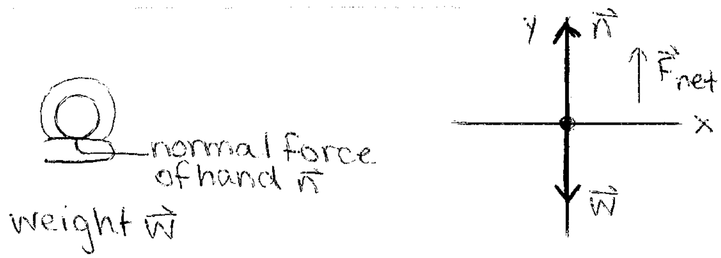


21. You are going to toss a rock *straight up* into the air by placing it on the palm of your hand (you're not gripping it), then pushing your hand up very rapidly. You may want to toss an object into the air this way to help you think about the situation. The rock is "the system" of interest.

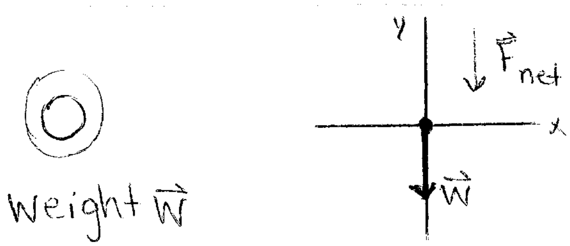
a. As you hold the rock at rest on your palm, before moving your hand.



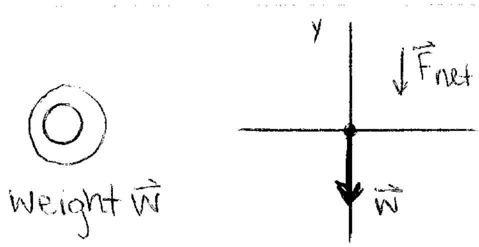
b. As your hand is moving up but before the rock leaves your hand.



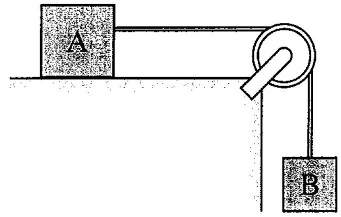
c. One-tenth of a second after the rock leaves your hand.

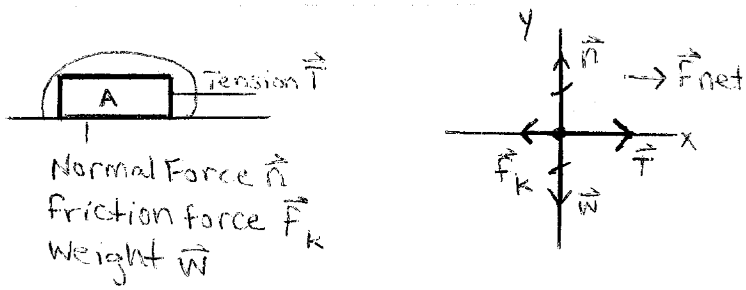


d. After the rock has reached its highest point and is now falling straight down.



22. Block B has just been released and is beginning to fall. Consider block A to be "the system."





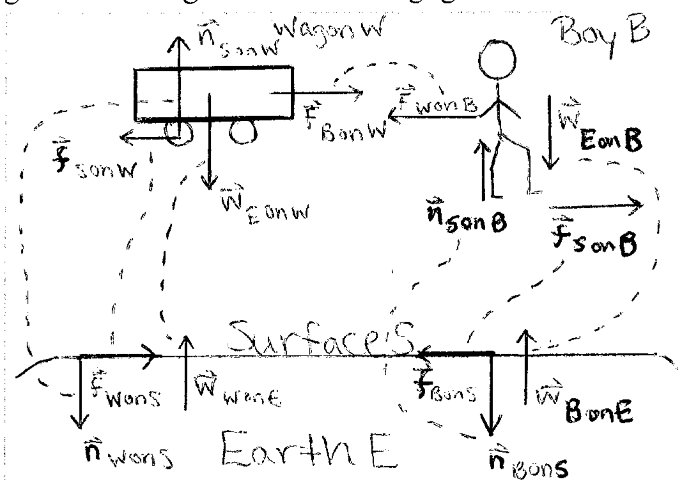
4.8 Newton's Third Law

Exercises 23–27: Apply the steps of Tactics Box 4.4 for identifying forces for interacting systems for each situation. That is,

- Identify the relevant objects in each case and draw a picture showing each relevant object separate from all other objects, but in the correct spatial orientation. Include the earth and, if appropriate, the earth's surface.
- Identify and label all forces as appropriate on the objects using the techniques of Tactics Box 4.2.
- Identify and label all action/reaction pairs using the notation $\vec{F}_{\text{A on B}}$.
- Draw a separate free-body diagram for each object and show the forces as **black** vectors.
- Connect all action/reaction pairs on the free-body diagrams with **red** dotted lines.

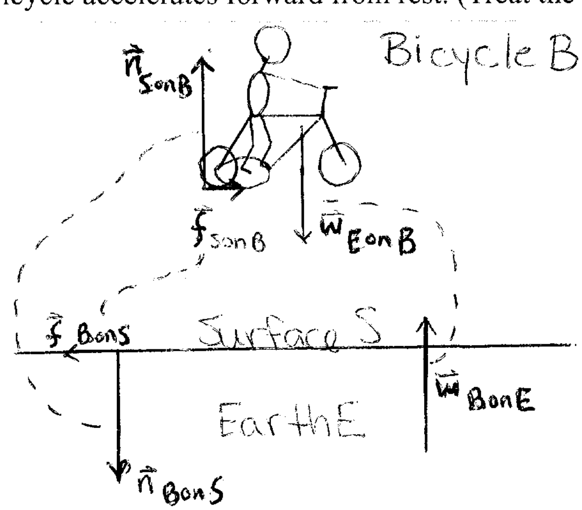
Note: Your pictures should look similar to Figure 4.34 in your text.

23. A boy pulls a wagon by a rope attached to the front of the wagon. The rope is parallel to the ground. Rolling friction is not negligible.



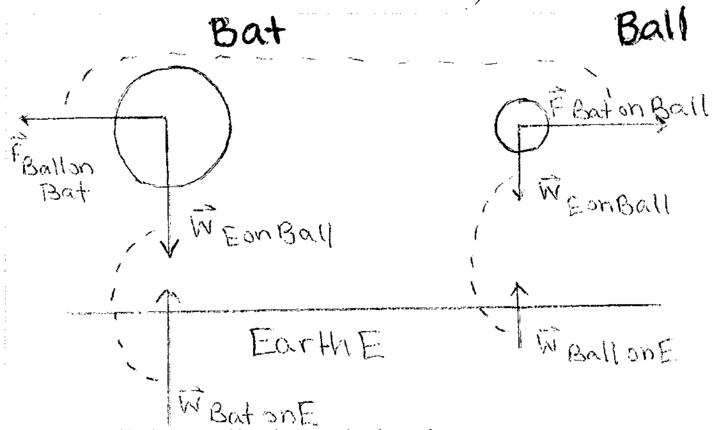
For simplicity, the normal and frictional forces are shown at only one contact point.

24. A bicycle accelerates forward from rest. (Treat the bicycle and its rider as a single object.)

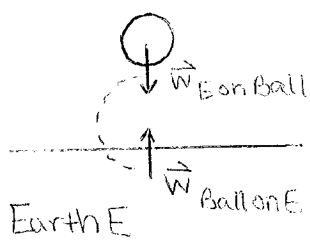


For simplicity, the normal and frictional forces are shown at only one contact point.

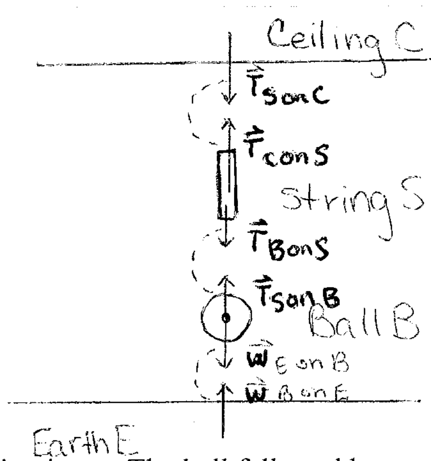
25. a. A bat hits a ball. (Draw your picture from the perspective of someone seeing the *end* of the bat at the moment it strikes the ball.)



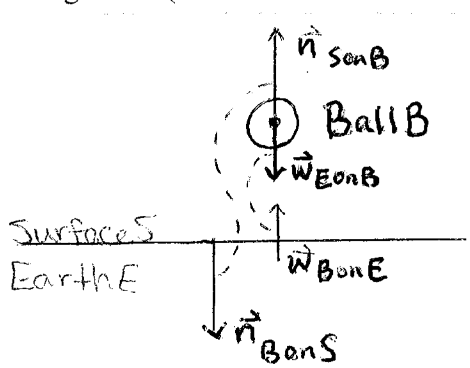
b. The ball then sails through the air.



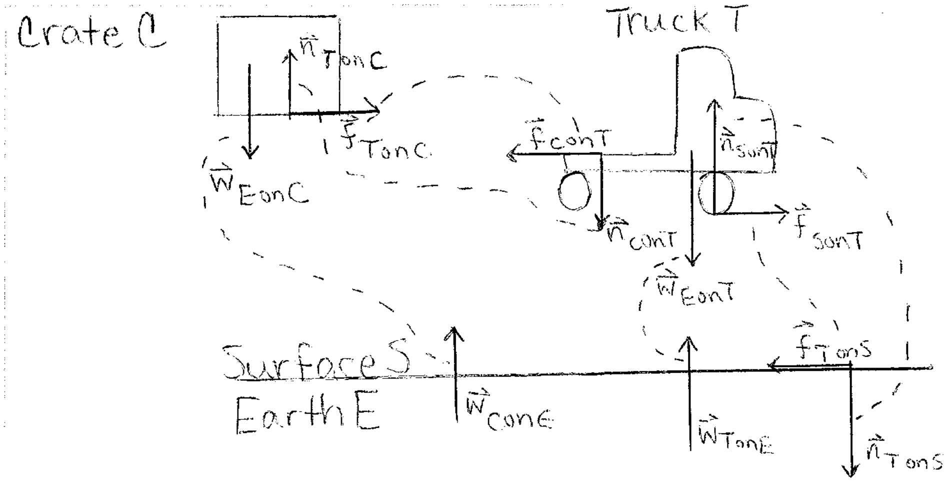
26. a. A ball hangs from a string. The string is attached to the ceiling.



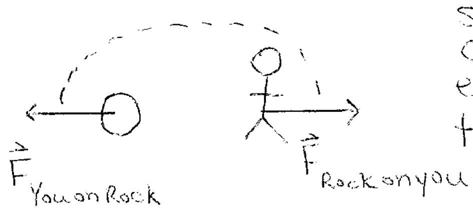
b. The string is cut. The ball falls and bounces. Consider the instant that the ball is in contact with the ground. (You don't need to show the string or the ceiling in part b.)



27. A crate is in the back of a truck as the truck accelerates forward. The crate does not slip. (Treat the crate and the truck as separate systems.)



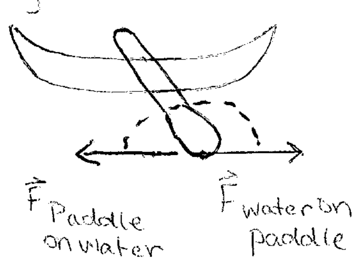
28. You find yourself in the middle of a frozen lake with a surface so slippery ($\mu_s = \mu_k = 0$) that you cannot walk. However, you happen to have several rocks in your pocket. The ice is extremely hard. It cannot be chipped, and the rocks slip on it just as much as your feet do. Can you think of a way to get to shore? Use pictures, forces, and Newton's laws to explain your reasoning.



Push the rocks away from the shore. When you exert a force on the rocks, they exert an equal but opposite force on you towards the shore according to Newton's third law.

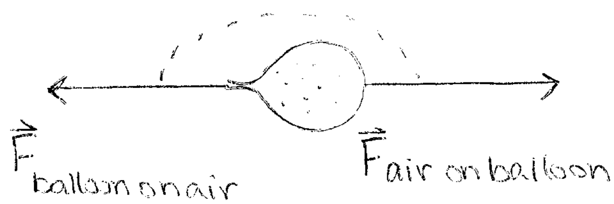
29. How do you paddle a canoe in the forward direction? Explain. Your explanation should include pictures showing forces on the water and forces on the paddle.

You push backwards on the water with the paddle and the water pushes forward on the paddle, accelerating it and the canoe.



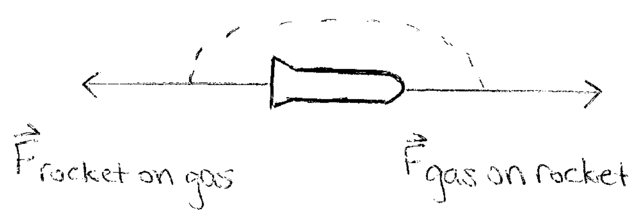
30. When you blow up a balloon and release it, it shoots forward. Explain why. Include pictures showing forces on the balloon and forces on the parcel of air that was just expelled from the balloon.

The stretched balloon pushes on the air, which leaves through the nozzle. The air pushes back on the balloon with an equal and opposite force.



31. How does a rocket take off? What is the upward force on it? Your explanation should include pictures showing forces on the rocket and forces on the parcel of hot gas that was just expelled from the rocket's exhaust.

A rocket takes off by ejecting exhaust gasses. The hot gas is forced out of the end of the rocket and it exherts a reaction force on the rocket in the opposite direction.



32. How do basketball players jump straight up into the air? Your explanation should include pictures showing forces on the player and forces on the ground.

When a basketball player straightens his legs, he exerts a force on the floor. The floor exerts an equal and opposite force back on the player.