4 Newton’s Second Law of Motion

Jill Johnsen of CCSF demonstrates ball drops in the opening photo of this chapter. Efrain Lopez, formerly from CCSF and now at California State University at Hayward, demonstrates equilibrium. Regarding the wingsuit skydiver in the center opening photo, I’m puzzled at the late date of this version of human flight. First we went to the Moon, then we discovered hang gliding, then bungee jumping, then maneuverable parachuting, and now, lastly, humans are doing what flying squirrels have been doing for eons! The order simply doesn’t make sense! The bottom photo is my granddaughter Emily at soccer practice.

The personal profile features Isaac Newton.

Inertia, acceleration, and falling objects as introduced in Chapters 2 and 3, and are further developed in this chapter. Here we distinguish between mass and weight without making a big deal about their units of measurement (because I think time is better spent on physics concepts). A brief treatment of units and systems of measurement is provided in Appendix A.

Practicing Physics Book:
- Mass and Weight
- Converting Mass to Weight
- A Day at the Races with $a = F/m$
- Dropping Masses and Accelerating
- Cart
- Force and Acceleration
- Friction
- Falling and Air Resistance
- Force-Vector Diagrams

Problem Solving Book:
More than 100 problems complement this chapter!

Laboratory Manual:
- The Weight *Mass and Weight* (Activity)
- Putting the Force Before the Cart *Force, Mass, and Acceleration* (Activity)
- Reaction Time *Free Fall* (Activity)
- The Newtonian Shot *Force and Motion Puzzle* (Activity)

Next-Time Questions (in the Instructor Resource DVD):
- Skidding Truck
- Spool Pull
- Falling Balls
- Skydiver
- Truck and Car Collision
- Block Pull
- Direction of Friction
- Book Push Against the Wall
- Acceleration at the Top
- Net Force Half-Way Up
- Acceleration on the Way Up
- Balanced Scale
- Galileo

Hewitt-Drew-It! Screencasts:
- *Mass/Weight*
- *Newton’s Second Law*
- *Acceleration Units*
- *Skydiver Problem*

SUGGESTED LECTURE PRESENTATION

In Chapter 2 the concept of inertia was introduced—the notion that once an object is in motion, it will continue in motion if no forces are exerted on it. Moving things tend to remain moving at constant velocity. In the previous chapter we learned about acceleration—the change in velocity that objects experience when a force *is* exerted. In this chapter we'll treat the relationship between force and acceleration.

Friction

Drag a block at constant velocity across your lecture table. Acknowledge the force of friction, and how it must exactly counter your pulling force. Show that pulling force with a spring balance. Now since the block moves without accelerating, ask for the magnitude of the friction force. It must be equal and opposite to your scale reading. Then the net force is zero. While sliding the block is in dynamic equilibrium. That is, $\Sigma F = 0$.

> CHECK QUESTIONS: (similar to one in the text.) Suppose in a high-flying airplane the captain announces over the cabin public address system that the plane is flying at a constant 900 km/h and the thrust of the engines is a constant 80,000 newtons. What is the acceleration of the airplane? [Answer: Zero, because velocity is constant.] What is the combined force of air resistance that acts all over the plane's outside surface? [Answer: 80,000 N. If it were less, the plane would speed up; if it were more, the plane would slow down.]

Continue your activity of pulling the block across the table with a spring balance. Show what happens when you pull harder. Your students see that when the pulling force is greater than the friction force, there is a net force greater than zero, as evidenced by the observed acceleration. Show different constant speeds across the table with the same applied force, which shows that friction is not dependent on speed. Distinguish between static and sliding friction, and show how a greater force is needed to get the block moving from a rest position. Show all this as you discuss these ideas. Cite the example in the book about skidding with locked brakes in a car [where the distance of skid for sliding friction is greater than static friction, where lower braking application results in nonsliding tires and shorter sliding distance]. Discuss the new automatic braking systems (ABS) of cars.

Friction in the **Practicing Physics Book** nicely treats details of friction.

After you have adequately discussed friction and net force, pose the following (Be careful that your class may not be ready for this, in which case you may confuse rather than enlighten.):

Mass and Weight

To distinguish between mass and weight compare the efforts of pushing horizontally on a block of slippery ice on a frozen pond versus lifting it. Or consider the weightlessness of a massive anvil in outer space and how it would be difficult to shake, weight or no weight. And if moving toward you, it would be harmful to be in its way because of its great tendency to remain in motion. The following demo (often used to illustrate impulse and momentum) makes the distinction nicely:

> DEMONSTRATION: Hang a massive ball by a string and show that the top string breaks when the bottom is pulled with gradually more force, but the bottom string breaks when the string is jerked. Ask which of these cases illustrates weight. [Interestingly enough, it's the weight of the ball that makes for the greater tension in the top string.] Then ask which of these cases illustrates inertia. [When jerked, the tendency of the ball to resist the sudden downward acceleration, its inertia, is responsible for the lower string breaking.] This is the best demo I know of for showing the different effects of weight and mass.

Mass Resists Acceleration: The property of massive objects to resist changes is nicely shown with this follow-up demonstration.

> DEMONSTRATION: Lie on your back and have an assistant place a blacksmith's anvil on your stomach. Have the assistant strike the anvil rather hard with a sledge hammer. The principles here are the same as the ball and string demo. Both the inertia of the ball and the inertia of the anvil

> resist the changes in motion they would otherwise undergo. So the string doesn't break, and your body is not squashed. (Be sure that your assistant is good with the hammer. When I began teaching I used to trust students to the task. In my fourth year the student who volunteered was extra nervous in front of the class and missed the anvil entirely—but not me. The hammer smashed into my hand breaking two fingers. I was lucky I was not harmed more.)

Relate the ideas of tightening a hammer head by slamming the opposite end of the handle on a firm surface, with the bones of the human spine after jogging or even walking around. Interestingly, we are similarly a bit shorter at night. Ask your students to find a place in their homes that they can't quite reach before going to bed—a place that is one or two centimeters higher than their reach.

Then tell them to try again when they awake the next morning. Unforgettable, for you are likely instructing them to discover something about themselves they were not aware of!

Newton's 2nd Law

Briefly review the idea of acceleration and its definition, and state that it is produced by an imposed force. Write this as $a \sim F$ and give examples of doubling the force and the resulting doubling of the acceleration, etc. Introduce the ideas of net force, with appropriate examples—like applying twice the force to a stalled car gives it twice as much acceleration—three times the force, three times the acceleration.

> CHECK QUESTION: If one were able to produce and maintain a constant net force of only 1 newton on the Queen Mary 2 ocean liner, what would be its maximum speed? Give multiple choices for an answer: a) 0 m/s; b) 1 m/s; c) less than 1 m/s; d) about 10 m/s; e) close to the speed of light! In the discussion that follows, the key concept is *net* force. Point out the enormous applied forces necessary to overcome the enormous water resistance at high speeds, to yield a *net force of 1 newton*; and the meaning of acceleration—that every succeeding second the ship moves a bit faster than the second before. This would go on seemingly without limit, except for relativistic effects which result in e) being the correct answer.

Falling Objects:

Point out that although Galileo introduced the idea of inertia, discussed the role of forces, and defined acceleration, he never tied these ideas together as Newton did with his second law. Although Galileo is credited as the first to demonstrate that in the absence of air resistance, falling objects fall with equal accelerations, he was not able to say why this is so. The answer is given by Newton's 2nd law.

> SKIT: Hold a heavy object like a kilogram weight and a piece of chalk with outstretched hands, ready to drop them. Ask your class which will strike the ground first if you drop them simultaneously. They know. Ask them to imagine you ask the same of a bright youngster, who responds by asking to handle the two objects before giving an answer. Pretend you are the kid judging the lifting of the two objects. "The metal object is heavier than chalk, which means there is more gravity force acting on it, which means it will accelerate to the ground before the chalk does." Write the kids argument in symbol notation on the board. $a \sim F$. Then go through the motions of asking the same of another child, who responds with a good argument that takes inertia rather than weight into account. This kid says, after shaking the metal and chalk back-and-forth in his or her hands, "The piece of metal is more massive than the chalk, which means it has more inertia, than the chalk, which means it will be harder to get moving than the chalk. So the chalk will race to the ground first, while the inertia of the metal causes it to lag behind." Write this kid's argument with, $a \sim 1/m$. State that a beauty of science is that such speculations can be ascertained by experiment. Drop the weight and the chalk to show that however sound each child's argument seemed to be, the results do not support either. Then bring both arguments together with $a \sim F/m$, Newton's 2nd law.

Relate your skit to the case of falling bricks, Figure 4.12, and the falling boulder and feather, Figure 4.13. Once these concepts are clear, ask how the bricks would slide on a frictionless inclined plane, then illustrate with examples such as the time required for a fully loaded roller coaster and an empty roller coaster to make a complete run. In the absence of friction effects, the times are the same. Cite the case of a Cadillac limousine and Volkswagen moving down a hill in the absence of friction. By now you are fielding questions having to do with air resistance and friction. (Avoid getting into the buoyancy of falling objects—information overload.)

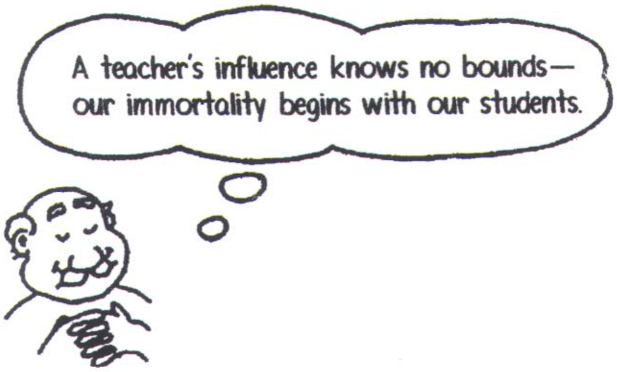
> DEMONSTRATION: After you have made clear the cases with no friction, then make a transition to practical examples that involve friction—leading off with the dropping of sheets of paper, one crumpled and one flat. Point out that the masses and weights are the same, and the only variable is air resistance. Bring in the idea of net force again, asking what the net force is when the paper falls at constant speed. (If you left the Chapter 3 demo of the falling book and paper on top of it unexplained, reintroduce it here.)
>
> CHECK QUESTIONS: What is the acceleration of a feather that "floats" slowly to the ground? The net force acting on the feather? If the feather weighs 0.0 N, how much air resistance acts upward against it? [Acceleration is zero at terminal speed, and air resistance = weight of object.]

These questions lead into a discussion of the parachutists in Figure 4.15. When the decrease of acceleration that builds up to terminal velocity is clear, return to the point earlier about the Cadillac and Volkswagen moving down an incline, only this time in the presence of air resistance. Then ask whether or not it would be advantageous to have a heavy cart or a light cart in a soap-box-derby race. Ask which would reach the finish line first if they were dropped through the air from a high-flying balloon. Then consider the carts on an inclined plane.

For your information, the terminal velocity of a falling baseball is about 150 km/h (95 mi/h), and for a falling Ping-Pong ball about 32 km/h (20 mi/h).

Make the distinction between how fast something hits the ground and with what force it hits. Dropping a pebble on one foot, and a boulder on the other makes this clear. Although they both hit at the same speed, the heavier boulder elicits the ouch!

So far we have regarded a force as a push or a pull. We will consider a deeper definition of force in the next chapter. Onward!



Answers and Solutions for Chapter 4

Reading Check Questions

1. Acceleration and net force are proportional to each other, not equal to each other.
2. Your push and the force of friction have the same magnitude.
3. Yes. As you increase your push, friction also increases just as much.
4. Once moving, your push has the same magnitude as the force of friction.
5. Static friction is greater than sliding friction for the same object.
6. Friction does not vary with speed.
7. Yes. Fluid friction does vary with speed.
8. Mass is more fundamental than weight.
9. mass; weight.
10. kilogram; newton.
11. A quarter-pound hamburger after it is cooked weighs about 1 newton.
12. The weight of a 1-kg brick is about 10 newtons.
13. Breaking of the top string is due mainly to the ball's weight.
14. Breaking of the lower string is due mainly to the ball's mass.
15. Acceleration is inversely proportional to mass.
16. The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.
17. No. Weight is proportional to mass, but not *equal* to mass.
18. The acceleration triples.
19. The acceleration decreases to one-third.
20. The acceleration will be unchanged.
21. The acceleration and net force are in the same direction.
22. In free fall, the only force acting on an object is the force of gravity.
23. The ratio of force to mass is g.
24. The ratio of force to mass for both is the same, g.
25. The net force is 10 N.
26. The net force is 6 N; zero.
27. Speed and frontal area affect the force of air resistance.
28. Acceleration is zero.
29. A heavier parachutist must fall faster for air resistance to balance weight.
30. The faster one encounters greater air resistance.

Think and Do

31. Relate how Newton followed Galileo, and so on.

32. The coin hits the ground first; when crumpled, both fall in nearly the same time; from an elevated starting point, the coin hits first. That's because it has less frontal area.

33. When the paper is on top of the dropped book, no air resistance acts on the paper because the book shields it from the air. So the paper and book fall with the same acceleration!

34. In all three kinds of motion they move in unison, in accord with $a = F/m$.

35. The spool will roll to the right! There is an angle at which it will not roll but slide. Any angle larger will roll the spool to the left. But pulled horizontally it rolls in the direction of the pull.

Plug and Chug

36. Weight = (50 kg)(10 N/kg) = 500 N.

37. Weight = (2000 kg)(10 N/kg) = 20,000 N.

38. Weight = (2.5 kg)(10 N/kg) = 25 N; (25 N)(2.2 lb/kg)(10 N/1 kg) = 550 N.

39. (1 N)(1 kg/10 N) = 0.1 kg; (0.1 kg)(2.2 lb/1 kg) = 0.22 lb.

40. N to kg; (300 N)(1 kg/10 N) = 30 kg.

41. $a = F_{\text{net}}/m$ = (500 N)/(2000 kg) = 0.25 N/kg = 0.25 m/s^2.

42. $a = F_{\text{net}}/m$ = (120,000 N)/(300,000 kg) = 0.4 N/kg = 0.4 m/s^2.

43. $a = F_{\text{net}}/m$ = 200 N/40 kg = 5 N/kg = 5 m/s^2.

44. $a = \Delta v/\Delta t$ = (6.0 m/s)/(1.2 m/s^2) = 5.0 m/s^2. .

45. **$a = F_{\text{net}}/m$ = (15 N)/(3.0 kg) = 5.0 N/kg = 5.0 m/s^2.**

46. **$a = F_{\text{net}}/m$ = (10 N)/(1 kg) = 10 N/kg = 10 m/s^2.**

47. $F_{\text{net}} = ma$ = (12 kg)(7.0 m/s^2) = 84 kg·m/s^2 = 84 N.

Think and Solve

48. (1 N)(1 lb/4.45 N) = 0.225 lb.

49. Lillian's mass is (500N)/(10N/kg) = 50 kg. Her weight in pounds, (50 kg)(2.2 lb/kg) = 110 lb.

50. The acceleration of each is the same: $a = F/m$ = 2 N/2 kg = 1 N/1 kg = 1 m/s^2. (Incidentally, from the definition that 1 N = 1 kg·m/s^2, you can see that 1 N/kg is the same as 1 m/s^2.)

51. For the jet: $a = F/m$ = 2(30,000 N)/(30,000 kg) = 2 m/s^2.

52. (a) $a = \Delta v/\Delta t$ = (9.0 m/s)/(0.2 s) = 45 m/s^2. (b) $F = ma$ = (100 kg)(45 m/s^2) = 4500 N.

53. (a) The force on the bus is Ma. New acceleration = same force/new mass = $Ma/(M+M/5) = 5Ma/(5M+M) = 5Ma/6M = (5/6)a$.
(b) New acceleration = $(5/6)a$ = (5/6)(1.2 m/s^2) = 1.0 m/s^2.

Think and Rank

54**.** a. D, A=B=C; b. A=C, B=D
55. C, B, A
56. a. A=B=C; b. C, A, B
57. a. C, A, B; b. B, A, C

Think and Explain

58. The force you exert on the ball ceases as soon as contact with your hand ceases.

59. Yes, if the ball slows down, a force opposite to its motion is acting—likely air resistance and friction between the ball and alley.

60. Constant velocity means zero acceleration, so yes, no net force acts on the motorcycle. But when moving at constant acceleration there is a net force acting on it.

61. No, inertia involves mass, not weight.

62. Items like apples weigh less on the Moon, so there are more apples in a 1-pound bag of apples there. Mass is another matter, for the same quantity of apples are in 1-kg bag on the Earth as on the Moon.

63. Buy by weight in Denver because the acceleration of gravity is less in Denver than in Death Valley. Buying by mass would be the same amount in both locations.

64. Shake the boxes. The box that offers the greater resistance to acceleration is the more massive box, the one containing the sand.

65. When you carry a heavy load there is more mass involved and a greater tendency to remain moving. If a load in your hand moves toward a wall, its tendency is to remain moving when contact is made. This tends to squash your hand if it's between the load and the wall—an unfortunate example of Newton's first law in action.

66. Mass is a measure of the amount of material in something, not gravitational pull that depends on its location. So although the weight of the astronaut may change with location, mass does not.

67. A massive cleaver is more effective in chopping vegetables because its greater mass contributes to greater tendency to keep moving as the cleaver chops the food.

68. Neither the mass nor the weight of a junked car changes when it is crushed. What does change is its volume, not to be confused with mass and weight.

69. Ten kilograms weighs about 100 N on the Earth (weight = mg = 10 kg $\times$ 10 m/s^2 = 100 N, or 98 N if g = 9.8 m/s^2 is used). On the Moon the weight is 1/6 of 100 N = 16.7 N (or 16 N if g = 9.8 m/s^2 is used). The mass is 10 kg everywhere.

70. The scale reading will increase during the throw. Your upward force on the heavy object is transmitted to the scale.

71. The change of weight is the change of mass times *g,* so when mass changes by 2 kg, weight changes by about 20 N.

72. One kg of mass weighs 2.2 pounds at the Earth's surface. If you weigh 100 pounds, for example, your mass is (100 lb)/(2.2 kg/lb) = 45 kg. Your weight in newtons, using the relationship weight = mg, is then (45 kg)(10 N/kg) = 450 N.

73. A 1-kg mass weighs 10 N, so 30 kg weigh 300 N. The bag can safely hold 30 kg of apples—if you don't pick it up too quickly.

74. Since the crate remains at rest, the net force on it is zero, which means the force of friction by the floor on the crate will be equal and opposite to your applied force.

75. The second law states the relationship between force and acceleration. If there is no net force, there is no acceleration—which is what Newton's first law states. So Newton's first law is consistent with the second law, and can be considered to be a special case of the second law.

76. Acceleration (slowing the car) is opposite to velocity (direction car moves).

77. Agree. Acceleration (slowing the car) is opposite to velocity (the direction the car is moving).

78. Acceleration is the ratio force/mass (Newton's second law), which in free fall is just weight/mass = $mg/m = g$. Since weight is proportional to mass, the ratio weight/mass is the same whatever the weight of a body.

79. Lifting the opponent decreases the force with which the ground supports him, and correspondingly decreases the force of friction he can muster. The reduced friction limits the opponent's effectiveness.

80. The forces acting horizontally are the driving force provided by friction between the tires and the road, and resistive forces—mainly air resistance. These forces cancel and the car is in dynamic equilibrium with a net force of zero.

81. (a) No. Air resistance is also acting. Free fall means free of all forces other than that due to gravity. A falling object may experience air resistance; a freely falling object experiences only the force due to gravity. (b) Yes. Although getting no closer to the Earth, the satellite is falling (more about this in Chapter 10).

82. The velocity of the ascending coin decreases while its acceleration remains constant (in the absence of air resistance).

83. The only force on a tossed coin, except for air resistance, is mg. So the same mg acts on the coin at all points in its trajectory.

84. The acceleration at the top or anywhere else in free fall is g, 10 m/s^2, downward. The velocity of the rock is momentarily zero while the rate of change of velocity is still present. Or better, by Newton's 2nd

law, the force of gravity acts at the top as elsewhere; divide this net force by the mass for the acceleration of free fall. That is, $a = F_{net}/m = mg/m = g$.

85. You explain the distinction between an applied force and a net force. It would be correct to say no *net* force acts on a car at rest.

86. When driving at constant velocity, the zero net force on the car results from the driving force that your engine supplies against the friction drag force. You continue to apply a driving force to offset the drag force that otherwise would slow the car.

87. When the apple is held at rest the upward support force equals the gravitational force on the apple and the net force is zero. When the apple is released, the upward support force is no longer there and the net force is the gravitational force, 1 N. (If the apple falls fast enough for air resistance to be important, then the net force will be less than 1 N, and eventually can reach zero if the air resistance builds up to 1 N.)

88. High-speed grains of sand grazing the Earth's atmosphere burn up because of friction against the air.

89. Both forces have the same magnitude. This is easier to understand if you visualize the parachutist at rest in a strong updraft—static equilibrium. Whether equilibrium is static or dynamic, the net force is zero.

90. When anything falls at constant velocity, air resistance and gravitational force are equal in magnitude. Raindrops are merely one example.

91. When a parachutist opens her chute she slows down. That means she accelerates upward.

92. There are usually two terminal speeds, one before the parachute opens, which is faster, and one after, which is slower. The difference has mainly to do with the different areas presented to the air in falling. The large area presented by the open chute results in a slower terminal speed, slow enough for a safe landing.

93. Just before a falling body attains terminal velocity, there is still a downward acceleration because gravitational force is still greater than air resistance. When the air resistance builds up to equal the gravitational force, terminal velocity is reached. Then air resistance is equal and opposite to gravitational force.

94. The terminal speed attained by the falling cat is the same whether it falls from 50 stories or 20 stories. Once terminal speed is reached, falling extra distance does not affect the speed. (The low terminal velocities of small creatures enables them to fall without harm from heights that would kill larger creatures.)

95. The sphere will be in equilibrium when it reaches terminal speed—which occurs when the gravitational force on it is balanced by an equal and opposite force of fluid drag.

96. Air resistance is not really negligible for so high a drop, so the heavier ball does strike the ground first. (This idea is shown in Figure 4.16.) But although a twice-as-heavy ball strikes first, it falls only a little faster, and not twice as fast, which is what followers of Aristotle believed. Galileo recognized that the small difference is due to air friction, and both would fall together when air friction is negligible.

97. The heavier tennis ball will strike the ground first for the same reason the heavier parachutist in Figure 4.15 strikes the ground first. Note that although the air resistance on the heavier ball is smaller relative to the ball's weight, it is actually greater than the air resistance that acts on the other ball. Why? Because the heavier ball falls faster, and air resistance is greater at greater speed.

98. Air resistance decreases the speed of a moving object. Hence the ball has less than its initial speed when it returns to the level from which it was thrown. The effect is easy to see for a feather projected upward by a slingshot. No way will it return to its starting point with its initial speed!

99. The ball rises in less time than it falls. If we exaggerate the circumstance and considering the feather example in the preceding answer, the time for the feather to flutter from its maximum altitude is clearly longer than the time it took to attain that altitude. The same is true for the not-so-obvious case of the ball.

100. Open-ended.

Think and Discuss

101. Yes, as illustrated by a ball thrown vertically into the air. Its velocity is initially upward, and finally downward, all the while accelerating at a constant downward g.

102. Neither a stick of dynamite nor anything else “contains” force. We will see later that a stick of dynamite contains *energy*, which is capable of producing forces when an interaction of some kind occurs.

103. No. An object can move in a curve only when a force acts. With no force its path would be a straight line.

104. The only force that acts on a dropped rock on the Moon is the gravitational force between the rock and the Moon because there is no air and therefore no air drag on the rock.

105. A dieting person seeks to lose mass. Interestingly, a person can lose weight by simply being farther from the center of the Earth, at the top of a mountain, for example.

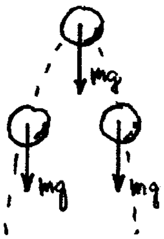
106. Friction between the crate and the truck-bed is the force that keeps the crate picking up the same amount of speed as the truck. With no friction, the accelerating truck would leave the crate behind.

107. Note that 30 N pulls three blocks. To pull two blocks then requires a 20-N pull, which is the tension in the rope between the second and third block. The tension in the rope that pulls only the third block is therefore 10 N. (Note that the net force on the first block,
30 N – 20 N = 10 N, is the force needed to accelerate that block, having one-third of the total mass.)

108. The *net* force on the wagon, your pull plus friction, is zero. So $\Sigma F = 0$.

109. When you stop suddenly, your velocity changes rapidly, which means a large acceleration of stopping. By Newton’s second law, this means the force that acts on you is also large. Experiencing a large force is what hurts you.

110. The force vector mg is the same at all locations. Acceleration g is therefore the same at all locations also.



111. Th t on the ground is greater. The ground must push up on you with a force greater than the downward force o

112. At the top of your jump your acceleration is g. Let the equation for acceleration via Newton’s second law guide your thinking: $a = F/m = mg/m = g$. If you said zero, you’re implying the force of gravity ceases to act at the top of your jump—not so!

113. For a decreasing acceleration the increase in speed becomes smaller each second, but nevertheless, there’s greater speed each second than in the preceding second.

114. The net force is mg downward, 10 N (or more precisely, 9.8 N).

115. The net force is 10 N – 2 N = 8 N (or more precisely 9.8 N – 2 N = 7.8 N).

116. Agree with your friend. Although acceleration decreases, the ball is nevertheless gaining speed. It will do so until it reaches terminal speed. Only then will it not continue gaining speed.

117. A sheet of paper presents a larger surface area to the air in falling (unless it is falling edge on), and therefore has a lower terminal speed. A wadded piece of paper presents a smaller area and therefore falls faster before reaching terminal speed.

118. In each case the paper reaches terminal speed, which means air resistance equals the weight of the paper. So air resistance will be the same on each! Of course the wadded paper falls faster for air resistance to equal the weight of the paper.

119. For low speeds, accelerations are nearly the same because air drag is small relative to the weights of the falling objects. From a greater height, there is time for air resistance to build up and more noticeably show its effects.

120. Sliding down at constant velocity means acceleration is zero and the net force is zero. This can occur if friction equals the bear's weight, which is 4000 N. Friction = bear's weight = mg = (400 kg)(10 m/ s^2) = 4000 N.

121. Nowhere is her velocity upward. The upward net force on Nellie during the short time that air resistance exceeds the force of gravity produces a momentary upward net force and upward acceleration. This produces a *decrease* in her downward speed, which is nevertheless still downward.