3 Linear Motion

The photo openers begin with my niece, Joan Lucas, riding her horse Ghost. The second photo is of my cherished friend from school days, Sue Johnson (wife of Dan Johnson) who with her racing-shell team won national honors in rowing. Shown also is Norwegian friend Carl Angell who rolls a ball through a photo timer. Also shown is friend and colleague from City College of San Francisco, Chelcie Liu, showing the tracks he made while teaching his daughter Cindy some physics. The tracks have been and are well used.

This chapter opens with a profile on Galileo.

TAKE CARE NOT TO SPEND OVERTIME ON THIS CHAPTER!! Doing so is the greatest pacing mistake in teaching physics! Time spent on kinematics is time not spent on why satellites continually fall without touching Earth, why high temperatures and high voltages (for the same reason) can be safe to touch, why rainbows are round, why the sky is blue, and how nuclear reactions keep the Earth's interior molten. Too much time on this chapter is folly. I strongly suggest making the distinction between speed, velocity, and acceleration, and move quickly to Chapter 4. (I typically spend only *one* class lecture on this chapter.) **By all means, avoid the temptation to do the classic motion problems that involve 90% math and 10% physics!** Too much treatment of motion analysis can be counterproductive to maintaining the interest in physics starting with the previous chapter. I suggest you tell your class that you're skimming the chapter so you'll have more time for more interesting topics in your course—let them know they shouldn't expect to master this material, and that mastery will be expected in later material (that doesn't have the stumbling blocks of kinematics). It's okay not to fully understand this early part of your course. Just as wisdom is knowing what to overlook, good teaching is knowing what to omit.

Perchance you are getting into more problem solving than is customary in a conceptual course, be sure to look at the student ancillary, *Problem Solving Book, 3rd Edition*. It has ample problems for a lightweight algebra-trigonometry physics course.

The box on *Hang Time* on page 50 may be especially intriguing to your students if they're unaware of the short time involved. Even basketball legend Michael Jordan's hang time was less than 0.9 s. Height jumped is less than 1.25 m (4 feet—those who insist a hang time of 2 s are way off, for 1 s up is 16 feet—clearly, no way!). A neat rule of thumb is that height jumped in feet, where $g = 32$ ft/s^2, is equal to four times hang time squared [$d = g/2(T/2)^2 = g/2(T^2/4) = 32/8(T^2) = 4T^2$].

I feel compelled to interject here (as I mean to stress all through this manual) the importance of the "check with your neighbor" technique of teaching. Please do not spend your lecture talking to yourself in front of your class! The procedure of "check with your neighbor" is a routine that keeps you and your class engaged. I can't stress enough its importance!

The distinction between velocity and acceleration is prerequisite to the following chapters on mechanics.

The **Practicing Physics Book** of worksheets treats the distinction between velocity acquired and distance fallen for free fall via a freely-falling speedometer-odometer. Students *do* learn from these, in class or out of class, so whether you have your students buy their own from your bookstore or you photocopy select pages for class distribution, get these to your students. There are four Practice Pages for this chapter:

• Free Fall Speed
• Acceleration of Free Fall
•Hang Time
• Non-Accelerated Motion

Problem Solving Book: Chapter 3 has abundant and insightful kinematics problems requiring straight-forward algebra, some with solutions.

Laboratory Manual:

• Go! Go! Go! *The Fundamentals of Graphing Motion* (Experiment)
• Sonic Ranger *Graphing Motion in Real Time* (Tech Lab)
• Motivating the Moving Man *Motion Graphing Simulation* (Tech Lab)

The textbook does not treat motion graphically, but leaves that to the laboratory manual. Labs are enhanced with the sonic ranger device, which is conceptual graphing at its best. If not done as lab experiments, demonstrate the sonic ranger as part of your lecture.

Next-Time Questions (in the Instructor Resource DVD):

• Relative Speeds
• Bikes and Bee

Hewitt-Drew-It! Screencasts: (All accessed via QR code in the text)

•*Free Fall*
•*Ball Toss*
•*Velocity Vectors*
•*Sideways Drop*
• *Bikes and Bee*

SUGGESTED LECTURE PRESENTATION

Your first question: What means of motion has done more to change the way cities are built than any other? [Answer: The elevator!]

Explain the importance of simplifying. Motion is best understood if you first neglect the effects of air resistance, the effects of buoyancy, spin, and the shape of moving objects—that beneath these are simple relationships that might otherwise be masked by "covering all bases," and that these *relationships* are what Chapter 3 and your lecture are about. State that by completely neglecting the effects of air resistance not only exposes the simple relationships, but is a reasonable assumption for heavy and compact (dense) objects traveling at moderate speeds; e.g., one would notice no difference between the rates of fall of a heavy rock dropped from the classroom ceiling to the floor below, when falling through either air or a complete vacuum. For a feather and heavy objects moving at high speeds, air resistance does become important, and will be treated in Chapter 4.

Mention that there are few pure examples in physics, for most real situations involve a combination of effects. There is usually a "first order" effect that is basic to the situation, but then there are 2^{nd}, 3^{rd}, and even 4^{th} or more order effects that interact also. If we begin our study of some concept by considering all effects together before we have studied their contributions separately, understanding is likely to be difficult. To have a better understanding of what is going on, we strip a situation of all but the first order effect, and then examine that. When that is well understood, then we proceed to investigate the other effects for a fuller understanding.

DEMONSTRATION: Drop a sheet of paper and note how slowly it falls because of air resistance. Crumple the paper and note it falls faster. Air resistance has been reduced. Then drop a sheet of paper and a book, side by side. Of course the book falls faster, due to its greater weight compared to air resistance. (Interestingly, the air drag is greater for the faster-falling book—an idea you'll return to in the next chapter.) Now place the paper against the lower surface of the raised horizontally-held book and when you drop them, nobody is surprised to see they fall together. The book has pushed the paper with it. Now repeat with the paper on *top* of the book and ask for predictions and neighbor discussion. Then surprise your class by refusing to show it! Tell them to try it out of class! (Good teaching isn't giving answers, but raising good questions—good enough to prompt wondering. Let students discover that the book will "plow through the air" leaving an air-resistance free path for the paper to follow!)

Air resistance will be treated in later chapters, but not this one. Again, simplifying brings out the concepts better. You can briefly acknowledge the important effects of air drag: In a bicycle race, for example, the lead cyclist carries along a flow of air that creates a "sweet spot" of low air pressure for the cyclist riding close behind. Air resistance on spinning balls changes their course, and so on. In keeping with the adage "Wisdom is knowing what to overlook," we neglect the effects of air in this chapter to more clearly reveal the connections between distance, time, speed, velocity, and acceleration. Let your students know that the effects of air drag are treated in future chapters.

Speed and Velocity

Define speed by writing its equation in longhand form on the board while giving examples—automobile speedometers, etc. Similarly define velocity, citing how a race car driver is interested in his *speed*, whereas an airplane pilot is interested in her *velocity*—speed and direction. Cite the difference between a scalar and a vector quantity and identify speed as a scalar and velocity as a vector. Tell your class that you're not going to make a big deal about distinguishing between speed and velocity, but you *are* going to make a big deal of distinguishing between velocity and another concept—*acceleration*.

Acceleration

Define acceleration by identifying it as a vector quantity, and cite the importance of CHANGE. That's change in speed, or change in direction. Hence both are acknowledged by defining acceleration as a rate of change in velocity rather than speed. Ask your students to identify the three controls in an automobile that make the auto *change* its state of motion—that produce *acceleration*. Ask for them (accelerator, brakes, and steering wheel). State how one lurches in a vehicle that is undergoing acceleration, especially for circular motion, and state why the definition of velocity includes direction to make the definition of acceleration all-encompassing. Talk of how without lurching one cannot sense motion, giving examples of coin flipping in a high-speed aircraft versus doing the same when the same aircraft is at rest.

Units for Acceleration: Give numerical examples of acceleration in units of kilometers/hour per second to establish the idea of acceleration. Be sure that your students are working on the examples with you. For example, ask them to find the acceleration of a car that goes from rest to 100 km/h in 10 seconds. It is important that you not use examples involving seconds twice until they taste success with the easier kilometers/hour per second examples. Have them check their work with their neighbors as you go along. Only after they get the hang of it, introduce meters/second/second in your examples to develop a sense for the units m/s^2. This is treated in the screencasts, *Unit Conversion* and *Acceleration Units*.

Falling Objects: If you round 9.8 m/s^2 to 10 m/s^2 in your lecture, you'll more easily establish the relationships between velocity and distance. In lab you can use the more precise 9.8 m/s^2.

CHECK QUESTION: If an object is dropped from an initial position of rest from the top of a cliff, how *fast* will it be traveling at the end of one second? (You might add, "Write the answer on your notepaper." And then, "Look at your neighbor's paper—if your neighbor doesn't have the right answer, reach over and help him or her—talk about it." And then possibly, "If your neighbor isn't very cooperative, sit somewhere else next time!")

After explaining the answer when class discussion dies down, repeat the process asking for the speed at the end of 2 seconds, and then for 10 seconds. This leads you into stating the relationship $v = gt$, which by now you can express in shorthand notation. After any questions, discussion, and examples, state that you are going to pose a different question—not asking of how *fast*, but for how *far*. Ask how far the object falls in one second. Ask for a written response and then ask if the students could explain to their neighbors *why* the distance is only 5 m rather than 10 m. After they've discussed this for almost a minute or so, ask "If you maintain a speed of 60 km/h for one hour, how far do you go?"—then, "If you maintain a speed of 10 m/s for one second, how far do you go?" Important point: You'll appreciably improve your instruction if you allow some thinking time after you ask a question. Not doing so is the folly of too many instructors. Then continue, "Then why is the answer to the first question not 10 meters?" After a suitable time, stress the idea of *average* velocity and the relation $d = v_{ave}t$.

Show the general case by deriving on the board $d = \frac{1}{2}gt^2$. (We tell our students that the derivation is a sidelight to the course—something that will be the crux of a follow-up physics course. In any event, the derivation is not something that we expect of them, but to show that $d = \frac{1}{2}gt^2$ is a reasoned statement that doesn't just pop up from nowhere.)

CHECK QUESTIONS: How far will a freely falling object that is released from rest, fall in 2 s? In 10 s? (When your class is comfortable with this, then ask how far in $\frac{1}{2}$ second.)

To avoid information overload, we restrict all numerical examples of free fall to cases that begin at rest. Why? Because it's simpler that way. (We prefer our students to understand simple physics than to be confused about not-so-simple physics!) We do go this far with them.

CHECK QUESTION: Consider a rifle fired straight downward from a high-altitude balloon. If the muzzle velocity is 100 m/s and air resistance can be neglected, what is the *acceleration* of the bullet after one second? (If most of your class say that it's *g*, you're on!)

I suggest *not* asking for the time of fall for a freely-falling object, given the distance. Why? Unless the distance given is the familiar 5 meters, algebraic manipulation is called for. If one of our teaching objectives were to teach algebra, this would be a nice place to do it. But we don't have time to present this stumbling block and then teach how to overcome it. We'd rather put our energy *and theirs* into straight physics!

Kinematics can be rich with puzzles, graphical analysis, ticker timers, photogates, and algebraic problems. My strong suggestion is to resist these and move quickly into the rest of mechanics, and then into other interesting areas of physics. Getting bogged down with kinematics, with so much physics ahead, is a widespread practice. Please do your class a favor and hurry on to the next chapters. If at the end of your course you have time (ha-ha), *then* bring out the kinematics toys and have a go at them.

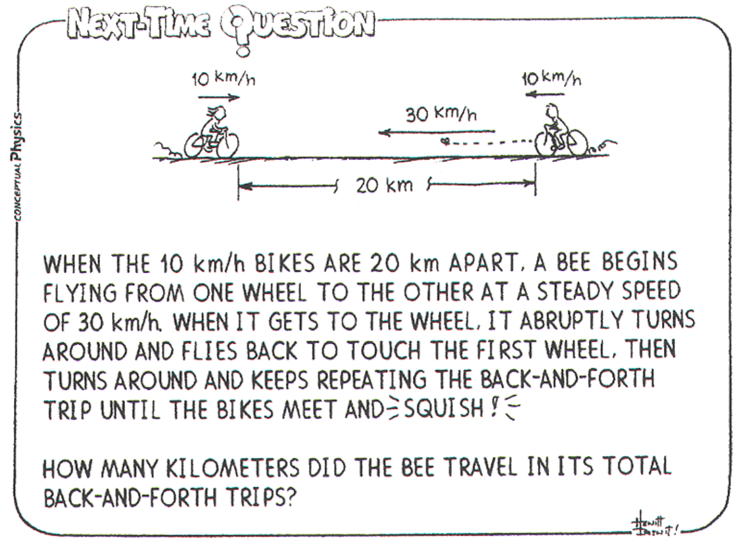
The Two-Track Demo

Be sure to fashion a pair of tracks like those shown by Chelcie Liu in the chapter opener photo. Chelcie simply bent a pair of angle iron used as bookcase supports. The tracks are of equal length and can be bent easily with a vice. Think and Discuss 95 and 96 refer to this demo. Be prepared for the majority of your class to say they reach the end of the track at the same time. Aha, they figure they have the same speed at the end, which throws them off base. Same *speed* does not mean same *time*. I like to quip "Which will win the race, the fast ball or the slower ball?" You can return to this demo when you discuss energy in Chapter 7.

Hang Time

As strange as it first may seem, the longest time a jumper can remain in air is less than a second. It is a common illusion that jumping times are more. Even Michael Jordan's best *hang time* (the time the feet are off the ground) was 0.9 second. Then $d = \frac{1}{2}gt^2$ predicts how high a jumper can go vertically. For a hang time of a full second, that's $\frac{1}{2}$ s up and $\frac{1}{2}$ s down. Substituting, $d = 5(0.5)^2 = 1.25$ m (which is about 4 feet!). So the great athletes and ballet dancers jump vertically no more than 4 feet high! Of course one can clear a higher fence or bar; but one's *center of gravity* cannot be raised more than 4 feet in free jumping. In fact very few people can jump 2 feet high! To test this, stand against a wall with arms upstretched. Mark the wall at the highest point. Then jump, and at the top, again mark the wall. For a human being, the distance between marks is at most 4 feet! We'll return to hang time for running jumps when we discuss projectile motion in Chapter 10.

NEXT-TIME QUESTION: For OHT or posting. Note the sample reduced pages from the *Next-Time Questions* book, full 8-$^1/_2$ × 11, just right for OHTs. Next-Time Questions for each chapter are on your Resource DVD, each with its answer. Consider displaying printed NTQs at some general area outside the classroom—perhaps in a glass case. This display generates general student interest, as students in your class and those not in your class are stimulated to think physics. After a few days of posting then turn the sheets over to reveal the answers. That's when new NTQs can be displayed. How better to adorn your corridors! Because of space limitations, those for other chapters are not shown in this manual. [I'm not showing the answer here, but it makes the point to solving this problem is consideration of time *t*. Whether or not one thinks about time should not be a matter of cleverness or good insight, but a matter of letting the equation for distance guide thinking. The *v* is given, but the time *t* is not. The equation instructs you to consider time. Equations are important in guiding our thinking about physics.]



Velocity Vectors
Consider Figure 3.12 of the airplane flying in a cross wind. The resulting speed can only be found with vectors. The only vector tools the student needs is the *parallelogram rule*, and perhaps the *Pythagorean Theorem*. Avoid sines and cosines unless your students are studying to be scientists or engineers. Here we distinguish between physics and the *tools* of physics. Tools for pre-engineers and scientists only. Physics for everybody!

This is a good time for the Hewitt-Drew-It Screencast *Velocity Vectors*, which treats an airplane flying at different directions relative to the wind.

Answers and Solutions for Chapter 3

Reading Check Questions

1. Relative to the chair your speed is zero. Relative to the Sun it's 30 km/s.
2. The two necessary units are distance traveled and time of travel.
3. A speedometer registers instantaneous speed.
4. Average speed is 30 km/min.
5. The horse travels 25 km/h x 0.5 h = 12.5 km.
6. Speed is a scalar and velocity is speed and direction, a vector.
7. Yes. A car moving at constant velocity moves at constant speed.
8. The car maintains a constant speed but not a constant velocity because it changes direction as it rounds the corner.
9. The acceleration is 10 km/h/s.
10. Acceleration is zero, because velocity doesn't change.
11. You are aware of changes in your speed, but not steady motion. Therefore you are aware of acceleration, but not constant velocity.
12. When motion is in one direction along a straight line, either may be used.
13. Galileo found that the ball gained the same amount of speed each second, which says the acceleration is constant.
14. Galileo discovered that the greater the angle of incline, the greater the acceleration. When the incline is vertical, the acceleration is that of free fall.
15. A freely-falling object is one on which the only force acting is the force of gravity. This means falling with no air resistance.
16. Gain in speed is 10 m/s each second.
17. The speed acquired in 5 seconds is 50 m/s; in 6 seconds, 60 m/s.
18. The unit 'seconds' occurs in velocity, and again in the time velocity is divided by to compute acceleration. Hence the square of seconds in acceleration.
19. The moving object loses 10 m/s for each second moving upward.
20. Galileo found distance traveled is directly proportional to the square of the time of travel ($d = \frac{1}{2} gt^2$).
21. The distance of fall in 1 second is 5 m. For a 4-s drop, falling distance is 80 m.
22. Air resistance reduces falling acceleration.
23. 10 m/s is speed, 10 m is distance, and 10 m/s^2 is acceleration.
24. The resultant is 141 km/h at an angle of 45° to the airplane's intended direction of travel.

Think and Do

25. Tell Grandma that, in effect, velocity is how fast you're traveling and acceleration is how quickly how-fast changes. Please don't tell Grandma that velocity is speed!

26. This can be a social activity, with good physics.

27. This is a follow-up to the previous activity, a good one!

28. Hang times will vary, but won't exceed 1 second!

Plug and Chug

29. Average speed $= \dfrac{\text{distance traveled}}{\text{time}} = \dfrac{\Delta d}{\Delta t} = \dfrac{30\ \text{m}}{2\ \text{s}} = 15\ \text{m/s}$.

30. Average speed $= \dfrac{\Delta d}{\Delta t} = \dfrac{1.0\ \text{m}}{0.5\ \text{s}} = 2\ \text{m/s}$

31. Acceleration $= \dfrac{\text{change in velocity}}{\text{time}} = \dfrac{\Delta v}{\Delta t} = \dfrac{100\ \text{km/h}}{10\ \text{s}} = 10\ \text{km/h} \cdot \text{s}$

32. Acceleration $= \dfrac{\text{change in velocity}}{\text{time}} = \dfrac{\Delta v}{\Delta t} = \dfrac{10\ \text{m/s}}{2\ \text{s}} = 5\ \text{m/s}^2$.

33. Starting from rest, distance = $\frac{1}{2} at^2 = \frac{1}{2} (5\ \text{m/s}^2)(3\ \text{s})^2 = 22.5\ \text{m}$.

34. Distance of fall = $\frac{1}{2} gt^2 = \frac{1}{2} (10\ \text{m/s}^2)(3\ \text{s})^2 = 45\ \text{m}$.

Think and Solve

35. Since it starts going up at 30 m/s and loses 10 m/s each second, its time going up is 3 seconds. Its time returning is also 3 seconds, so it's in the air for a total of 6 seconds. Distance up (or down) is $\frac{1}{2}gt^2 = 5 \times 3^2 = 45$ m. Or from $d = vt$, where average velocity is (30 + 0)/2 = 15 m/s, and time is 3 seconds, we also get $d = 15 \text{ m/s} \times 3 \text{ s} = 45$ m.

36. (a) The velocity of the ball at the top of its vertical trajectory is instantaneously zero.
(b) Once second before reaching its top, its velocity is **10 m/s**.
(c) The amount of change in velocity is **10 m/s** during this 1-second interval (or any other 1-second interval).
(d) One second after reaching its top, its velocity is **-10 m/s**—equal in magnitude but oppositely directed to its value 1 second before reaching the top.
(e) The amount of change in velocity during this (or any) 1-second interval is 10 m/s.
(f) In 2 seconds, the amount of change in velocity, from 10 m/s up to 10 m/s down, is **20 m/s** (not zero!).
(g) The acceleration of the ball is **10 m/s²** before reaching the top, when reaching the top, and after reaching the top. In all cases acceleration is downward, toward the Earth.

37. Using $g = 10 \text{ m/s}^2$, we see that $v = gt = (10 \text{ m/s}^2)(10 \text{ s}) = 100$ m/s;

$$v_{av} = \frac{(v_{beginning} + v_{final})}{2} = \frac{(0 + 100)}{2} = \mathbf{50\ m/s}\text{, downward.}$$

We can get "how far" from either $d = v_{av}t = (50 \text{ m/s})(10 \text{ s}) =$ **500 m**, or equivalently, $d = \frac{1}{2}gt^2 = 5(10)^2 = 500$ m. (How nice we get the same distance using either formula!)

38. $a = \dfrac{\Delta v}{\Delta t} = \dfrac{25 \text{ m/s} - 0}{10 \text{ m/s}} = 2.5 \text{ m/s}^2.$

39. From $d = \frac{1}{2}gt^2 = 5t^2$, $t = \sqrt{d/5} = \sqrt{0.6/5} = 0.35$ s. Doubling for a hang time of **0.7 s**.

40. a. $t = ?$ From $\bar{v} = \dfrac{d}{t} \Rightarrow t = \dfrac{d}{\bar{v}} = \dfrac{L}{(v_f + v_0)/2} = \dfrac{2L}{v}.$

b. $t = \dfrac{2L}{v} = \dfrac{2(1.4 \text{ m})}{15.0 \text{ m/s}} = 0.19\text{s}.$

Think and Rank

41. D, C, A, B
42. C, B=D, A
43. a. B, A=C
    b. A, B, C
    c. C, B, A
44. a. C, B, A
    b. A=B=C (10 m/s²)
45. B, A, C
46. a. B, A, C
    b. C, B, A

Think and Explain

47. The shorter the better, so Mo has the more favorable reaction time and can respond quicker to situations than Jo can.

48. Jo travels 1.2 m during the time between seeing the emergency and applying the brakes.
$d = vt = 6 \text{ m/s} \times 0.20 \text{ s} = 1.2$ m.

49. The impact speed will be the relative speed, 2 km/h (100 km/h – 98 km/h = 2 km/h).

50. She'll be unsuccessful. Her velocity relative to the shore is zero (8 km/h – 8 km/h = 0).

51. Your fine for speeding is based on your instantaneous speed; the speed registered on a speedometer or a radar gun.

52. The speeds of both are exactly the same, but the velocities are not. Velocity includes direction, and since the directions of the airplanes are opposite, their velocities are opposite. The velocities would be equal only if both speed and direction were the same.

53. Constant velocity means no acceleration, so the acceleration of light is zero.

54. The car approaches you at twice the speed limit.

55. (a) Yes, because of the change of direction. (b) Yes, because velocity changes.

56. Emily is correct. Jacob is describing speed. Acceleration is the time rate of change in speed—"how fast you get fast," as Emily asserts.

57. No. You cannot say which car underwent the greater acceleration unless you know the times involved.

58. The acceleration is zero, for no change in velocity occurs. Whenever the change in velocity is zero, the acceleration is zero. If the velocity is "steady," "constant," or "uniform," the change in velocity is zero. Remember the definition of acceleration!

59. The greater change in speeds occurs for (30 km/h − 25 km/h = 5 km/h), which is greater than (100 km/h − 96 km/h = 4 km/h). So for the same time, the slower one has the greater acceleration.

60. At 0° the acceleration is zero. At 90° the acceleration is that of free fall, *g*. So the range of accelerations is 0 to *g*, or 0 to 10 m/s^2.

61. Its speed readings would increase by 10 m/s each second.

62. Distance readings would indicate greater distances fallen in successive seconds. During each successive second the object falls faster and covers greater distance.

63. The acceleration of free fall at the end of the 5^{th}, 10^{th}, or any number of seconds is *g*. Its *velocity* has different values at different times, but since it is free from the effects of air resistance, its *acceleration* remains a constant *g*.

64. In the absence of air resistance, the acceleration will be *g* no matter how the ball is released. The acceleration of a ball and its speed are entirely different.

65. Whether up or down, the rate of change of speed with respect to time is 10 m/s^2, so each second while going up the speed decreases by 10 m/s. Coming down, the speed increases by 10 m/s each second. So with no air resistance, the time rising equals the time falling.

66. With no air resistance, both will strike the ground below at the same speed. Note that the ball thrown upward will pass its starting point on the way down with the same speed it had when starting up. So its trip on downward, below the starting point, is the same as for a ball thrown down with that speed.

67. When air resistance affects motion, the ball thrown upward returns to its starting level with less speed than its initial speed; and also less speed than the ball tossed downward. So the downward thrown ball hits the ground below with a greater speed.

68. Counting to twenty means twice the time. In twice the time the ball will roll 4 times as far (distance moved is proportional to the square of the time).

69. The acceleration due to gravity remains a constant *g* at all points along its path as long as no other forces like air drag act on the projectile.

70.

Time (in seconds)	Velocity (in meters/second)	Distance (in meters)
0	0	0
1	10	5
2	20	20
3	30	45
4	40	80
5	50	125

6	60	180
7	70	245
8	80	320
9	90	405
10	100	500

71. If it were not for the slowing effect of the air, raindrops would strike the ground with the speed of high-speed bullets!

72. No, free-fall acceleration is constant, which accounts for the constant increase of falling speed.

73. Air drag decreases speed. So a tossed ball will return with less speed than it possessed initially.

74. On the Moon the acceleration due to gravity is considerably less, so hang time would be considerably more (six times more for the same takeoff speed!).

75. As water falls it picks up speed. Since the same amount of water issues from the faucet each second, it stretches out as distance increases. It becomes thinner just as taffy that is stretched gets thinner the more it is stretched. When the water is stretched too far, it breaks up into droplets.

76. The speed of falling rain and the speed of the automobile are the same.

77. Open ended.

78. Open ended.

Think and Discuss

79. Yes. Velocity and acceleration need not be in the same direction. A car moving north that slows down, for example, accelerates toward the south.

80. Yes, again, velocity and acceleration need not be in the same direction. A ball tossed upward, for example, reverses its direction of travel at its highest point while its acceleration g, directed downward, remains constant (this idea will be explained further in Chapter 4). Note that if a ball had zero acceleration at a point where its speed is zero, its speed would *remain* zero. It would sit still at the top of its trajectory!

81. Acceleration occurs when the speedometer reading changes. No change, no acceleration.

82. "The dragster rounded the curve at a constant speed of 100 km/h." Constant velocity means not only constant speed but constant direction. A car rounding a curve changes its direction of motion.

83. Any object moving in a circle or along a curve is changing its velocity (accelerating) even if its speed is constant, because direction is changing. Something with constant velocity has both constant direction *and* constant speed, so there is no example of motion with constant velocity and varying speed.

84. A vertically-thrown ball has zero speed at the top of its trajectory, but acceleration there is g.

85. An object moving in a circular path at constant speed is a simple example of acceleration at constant speed because its velocity is changing direction. No example can be given for the second case, because constant velocity means zero acceleration. You can't have a nonzero acceleration while having a constant velocity. There are no examples of things that accelerate while not accelerating.

86. (a) Yes. For example, an object sliding or rolling horizontally on a frictionless plane. (b) Yes. For example, a vertically thrown ball at the top of its trajectory.

87. The acceleration of an object is in a direction opposite to its velocity when velocity is decreasing—for example, a ball rising or a car braking to a stop.

88. Only on the middle hill does speed along the path decrease with time, for the hill becomes less steep as motion progresses. When the hill levels off, acceleration will be zero. On the left hill, acceleration is constant. On the right hill, acceleration increases as the hill becomes steeper. In all three cases, speed increases.

89. The one in the middle. The ball gains speed more quickly at the beginning where the slope is steeper, so its average speed is greater even though it has less acceleration in the last part of its trip.

90. Free fall is defined as falling only under the influence of gravity, with *no* air resistance or other non-gravitational forces. So your friend should omit “free” and say something like, “Air resistance is more effective in slowing a falling feather than a falling coin.”

91. If air resistance is not a factor, an object’s acceleration is the same 10 m/s^2 regardless of its initial velocity. If it is thrown downward, its velocity will be greater, but not its acceleration.

92. Its acceleration would actually be less if the air resistance it encounters at high speed retards its motion. (We will treat this concept in detail in Chapter 4.)

93. When acceleration of the car is in a direction opposite to its velocity, the car is “decelerating,” slowing down.

94. In the absence of air resistance both accelerations are *g*, the same. Their velocities may be in opposite directions, but *g* is the same for both.

95. The ball on B finishes first, for its average speed along the lower part as well as the down and up slopes is greater than the average speed of the ball along track A.

96. (a) Average speed is greater for the ball on track B.
(b) The instantaneous speed at the ends of the tracks is the same because the speed gained on the down-ramp for B is equal to the speed lost on the up-ramp side. (Many people get the wrong answer for the previous question because they assume that because the balls end up with the same speed that they roll for the same time. Not so.)

97. The resultant speed is indeed 5 m/s. The resultant of any pair of 3-unit and 4-unit vectors at right angles to each other is 5 units. This is confirmed by the Pythagorean theorem;
$a^2 + b^2 = c^2$ gives $3^2 + 4^2 = 5^2$. (Or, $\sqrt{[3^2 + 4^2]} = 5$.)

98. Again, from the Pythagorean theorem; $a^2 + b^2 = c^2$ gives $3^2 + 4^2 = 5^2$. (Or, $\sqrt{[3^2 + 4^2]} = 5$.) So the boat has a speed of 5 m/s.

99. Again, from the Pythagorean theorem; $a^2 + b^2 = c^2$ gives $120^2 + 90^2 = 150^2$.
(Or, $\sqrt{[120^2 + 90^2]} = 150$.) So the groundspeed is 150 km/h.

100. How you respond may or may not agree with the author’s response: There are few pure examples in physics, for most real situations involve a combination of effects. There is usually a “first order” effect that is basic to the situation, but then there are 2nd, 3rd, and even 4th or more order effects that interact also. If we begin our study of some concept by considering all effects together before we have studied their contributions separately, understanding is likely to be difficult. To have a better understanding of what is going on, we strip a situation of all but the first order effect, and then examine that. When we have a good understanding of that, then we proceed to investigate the other effects for a fuller understanding. Consider Kepler, for example, who made the stunning discovery that planets move in elliptical paths. Now we know that they don’t quite move in perfect ellipses because each planet affects the motion of every other one. But if Kepler had been stopped by these second-order effects, he would not have made his groundbreaking discovery. Similarly, if Galileo hadn’t been able to free his thinking from real-world friction he may not have made his great discoveries in mechanics.