EXERCISE D A car starts from rest and accelerates at a constant $10\ \text{m/s}^2$ during a $\frac{1}{4}$-mile (402 m) race. How fast is the car going at the finish line? (*a*) 8040 m/s; (*b*) 90 m/s; (*c*) 81 m/s; (*d*) 804 m/s.

2–6 Solving Problems

Before doing more worked-out Examples, let us look at how to approach problem solving. First, it is important to note that physics is *not* a collection of equations to be memorized. Simply searching for an equation that might work can lead you to a wrong result and will not help you understand physics (Fig. 2–14). A better approach is to use the following (rough) procedure, which we present as a special "Problem Solving Strategy." (Other such Problem Solving Strategies will be found throughout the book.)

FIGURE 2–14 Read the book, study carefully, and work the Problems using your reasoning abilities.

PROBLEM SOLVING

1. Read and **reread** the whole problem carefully before trying to solve it.
2. Decide what **object** (or objects) you are going to study, and for what **time interval**. You can often choose the initial time to be $t = 0$.
3. **Draw** a **diagram** or picture of the situation, with coordinate axes wherever applicable. [You can place the origin of coordinates and the axes wherever you like to make your calculations easier. You also choose which direction is positive and which is negative. Usually we choose the x axis to the right as positive.]
4. Write down what quantities are "**known**" or "given," and then what you *want* to know. Consider quantities both at the beginning and at the end of the chosen time interval. You may need to "translate" language into physical terms, such as "starts from rest" means $v_0 = 0$.
5. Think about which **principles of physics** apply in this problem. Use common sense and your own experiences. Then plan an approach.
6. Consider which **equations** (and/or definitions) relate the quantities involved. Before using them, be sure their **range of validity** includes your problem (for example, Eqs. 2–11 are valid only when the acceleration is constant). If you find an applicable equation that involves only known quantities and one desired unknown, **solve** the equation algebraically for the unknown. Sometimes several sequential calculations, or a combination of equations, may be needed. It is often preferable to solve algebraically for the desired unknown before putting in numerical values.
7. Carry out the **calculation** if it is a numerical problem. Keep one or two extra digits during the calculations, but round off the final answer(s) to the correct number of significant figures (Section 1–4).
8. Think carefully about the result you obtain: Is it **reasonable**? Does it make sense according to your own intuition and experience? A good check is to do a rough **estimate** using only powers of 10, as discussed in Section 1–7. Often it is preferable to do a rough estimate at the *start* of a numerical problem because it can help you focus your attention on finding a path toward a solution.
9. A very important aspect of doing problems is keeping track of **units**. An equals sign implies the units on each side must be the same, just as the numbers must. If the units do not balance, a mistake has been made. This can serve as a **check** on your solution (but it only tells you if you're wrong, not if you're right). Always use a consistent set of units.

EXAMPLE 2–8 **Acceleration of a car.** How long does it take a car to cross a 30.0-m-wide intersection after the light turns green, if the car accelerates from rest at a constant $2.00\ \mathrm{m/s^2}$?

PROBLEM SOLVING
"Starting from rest" means $v = 0$ at $t = 0$ [i.e., $v_0 = 0$]

APPROACH We follow the Problem Solving Strategy on the previous page, step by step.

SOLUTION

1. **Reread** the problem. Be sure you understand what it asks for (here, a time interval: "how long does it take").
2. The **object** under study is the car. We need to choose the **time interval** during which we look at the car's motion: we choose $t = 0$, the initial time, to be the moment the car starts to accelerate from rest $(v_0 = 0)$; the time t is the instant the car has traveled the full 30.0-m width of the intersection.
3. **Draw** a **diagram**: the situation is shown in Fig. 2–15, where the car is shown moving along the positive x axis. We choose $x_0 = 0$ at the front bumper of the car before it starts to move.

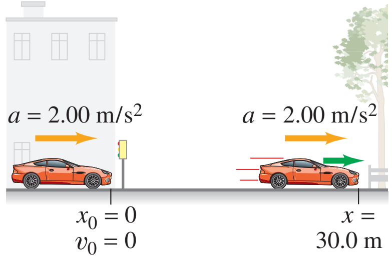


FIGURE 2–15 Example 2–8.

Known	Wanted
$x_0 = 0$	t
$x = 30.0\ \mathrm{m}$	
$a = 2.00\ \mathrm{m/s^2}$	
$v_0 = 0$	

4. The "**knowns**" and the "wanted" information are shown in the Table in the margin. Note that "starting from rest" means $v = 0$ at $t = 0$; that is, $v_0 = 0$. The wanted time t is how long it takes the car to travel 30.0 m.
5. The **physics**: the car, starting from rest $(\text{at } t_0 = 0)$, increases in speed as it covers more distance. The acceleration is constant, so we can use the kinematic equations, Eqs. 2–11.
6. **Equations**: we want to find the time, given the distance and acceleration; Eq. 2–11b is perfect since the only unknown quantity is t. Setting $v_0 = 0$ and $x_0 = 0$ in Eq. 2–11b $\left(x = x_0 + v_0 t + \frac{1}{2}at^2\right)$, we have
$$x = \tfrac{1}{2}at^2.$$
We solve for t by multiplying both sides by $\dfrac{2}{a}$:
$$\frac{2x}{a} = t^2.$$
Taking the square root, we get t:
$$t = \sqrt{\frac{2x}{a}}.$$
7. The **calculation**:
$$t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2(30.0\ \mathrm{m})}{2.00\ \mathrm{m/s^2}}} = 5.48\ \mathrm{s}.$$
This is our answer. Note that the units come out correctly.
8. We can check the **reasonableness** of the answer by doing an alternate calculation: we first find the final velocity
$$v = at = \left(2.00\ \mathrm{m/s^2}\right)(5.48\ \mathrm{s}) = 10.96\ \mathrm{m/s},$$
and then find the distance traveled
$$x = x_0 + \bar{v}t = 0 + \tfrac{1}{2}(10.96\ \mathrm{m/s} + 0)(5.48\ \mathrm{s}) = 30.0\ \mathrm{m},$$
which checks with our given distance.
9. We checked the **units** in step 7, and they came out correctly (seconds).

PROBLEM SOLVING
Check your answer

NOTE In steps 6 and 7, when we took the square root, we should have written $t = \pm\sqrt{2x/a} = \pm 5.48\ \mathrm{s}$. Mathematically there are two solutions. But the second solution, $t = -5.48\ \mathrm{s}$, is a time *before* our chosen time interval and makes no sense physically. We say it is "unphysical" and ignore it.

PROBLEM SOLVING
"Unphysical" solutions

We explicitly followed the steps of the Problem Solving Strategy in Example 2–8. In upcoming Examples, we will use our usual "Approach" and "Solution" to avoid being wordy.

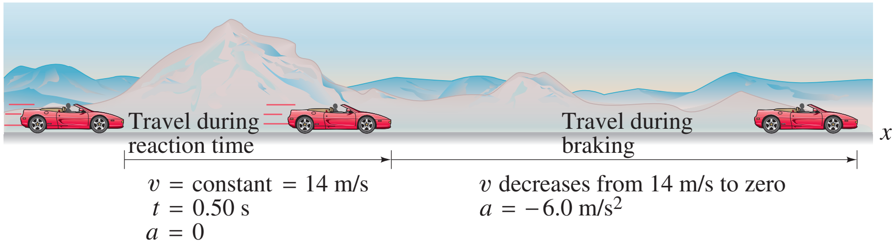


FIGURE 2–16 Example 2–9: stopping distance for a braking car.

PHYSICS APPLIED
Car stopping distances

EXAMPLE 2–9 ESTIMATE **Braking distances.** Estimate the minimum stopping distance for a car, which is important for traffic safety and traffic design. The problem is best dealt with in two parts, two separate time intervals. (1) The first time interval begins when the driver decides to hit the brakes, and ends when the foot touches the brake pedal. This is the "reaction time" during which the speed is constant, so $a = 0$. (2) The second time interval is the actual braking period when the vehicle slows down $(a \neq 0)$ and comes to a stop. The stopping distance depends on the reaction time of the driver, the initial speed of the car (the final speed is zero), and the deceleration of the car. For a dry road and good tires, good brakes can decelerate a car at a rate of about $5\ \mathrm{m/s^2}$ to $8\ \mathrm{m/s^2}$. Calculate the total stopping distance for an initial velocity of 50 km/h $(= 14\ \mathrm{m/s} \approx 31\ \mathrm{mi/h})$ and assume the acceleration of the car is $-6.0\ \mathrm{m/s^2}$ (the minus sign appears because the velocity is taken to be in the positive x direction and its magnitude is decreasing). Reaction time for normal drivers varies from perhaps 0.3 s to about 1.0 s; take it to be 0.50 s.

APPROACH During the "reaction time," part (1), the car moves at constant speed of 14 m/s, so $a = 0$. Once the brakes are applied, part (2), the acceleration is $a = -6.0\ \mathrm{m/s^2}$ and is constant over this time interval. For both parts a is constant, so we can use Eqs. 2–11.

Part 1: Reaction time

Known	Wanted
$t = 0.50\ \mathrm{s}$	x
$v_0 = 14\ \mathrm{m/s}$	
$v = 14\ \mathrm{m/s}$	
$a = 0$	
$x_0 = 0$	

SOLUTION Part (1). We take $x_0 = 0$ for the first time interval, when the driver is reacting (0.50 s): the car travels at a constant speed of 14 m/s so $a = 0$. See Fig. 2–16 and the Table in the margin. To find x, the position of the car at $t = 0.50\ \mathrm{s}$ (when the brakes are applied), we cannot use Eq. 2–11c because x is multiplied by a, which is zero. But Eq. 2–11b works:

$$x = v_0 t + 0 = (14\ \mathrm{m/s})(0.50\ \mathrm{s}) = 7.0\ \mathrm{m}.$$

Thus the car travels 7.0 m during the driver's reaction time, until the instant the brakes are applied. We will use this result as input to part (2).

Part 2: Braking

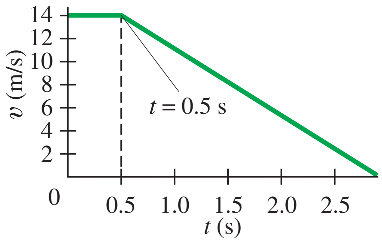
Known	Wanted
$x_0 = 7.0\ \mathrm{m}$	x
$v_0 = 14\ \mathrm{m/s}$	
$v = 0$	
$a = -6.0\ \mathrm{m/s^2}$	

Part (2). During the second time interval, the brakes are applied and the car is brought to rest. The initial position is $x_0 = 7.0\ \mathrm{m}$ (result of part (1)), and other variables are shown in the second Table in the margin. Equation 2–11a doesn't contain x; Eq. 2–11b contains x but also the unknown t. Equation 2–11c, $v^2 - v_0^2 = 2a(x - x_0)$, is what we want; after setting $x_0 = 7.0\ \mathrm{m}$, we solve for x, the final position of the car (when it stops):

$$\begin{aligned} x &= x_0 + \frac{v^2 - v_0^2}{2a} \\ &= 7.0\ \mathrm{m} + \frac{0 - (14\ \mathrm{m/s})^2}{2(-6.0\ \mathrm{m/s^2})} = 7.0\ \mathrm{m} + \frac{-196\ \mathrm{m^2/s^2}}{-12\ \mathrm{m/s^2}} \\ &= 7.0\ \mathrm{m} + 16\ \mathrm{m} = 23\ \mathrm{m}. \end{aligned}$$

The car traveled 7.0 m while the driver was reacting and another 16 m during the braking period before coming to a stop, for a total distance traveled of 23 m. Figure 2–17 shows a graph of v vs. t: v is constant from $t = 0$ until $t = 0.50\ \mathrm{s}$, and after $t = 0.50\ \mathrm{s}$ it decreases linearly to zero.

FIGURE 2–17 Example 2–9. Graph of v vs. t.



NOTE From the equation above for x, we see that the stopping distance after the driver hit the brakes $(= x - x_0)$ increases with the *square* of the initial speed, not just linearly with speed. If you are traveling twice as fast, it takes four times the distance to stop.