Automobile engines do work to overcome the force of friction (including air resistance), to climb hills, and to accelerate. A car is limited by the rate at which it can do work, which is why automobile engines are rated in horsepower. A car needs power most when climbing hills and when accelerating. In the next Example, we will calculate how much power is needed in these situations for a car of reasonable size. Even when a car travels on a level road at constant speed, it needs some power just to do work to overcome the retarding forces of internal friction and air resistance. These forces depend on the conditions and speed of the car, but are typically in the range 400 N to 1000 N.

It is often convenient to write power in terms of the net force F applied to an object and its speed v. This is readily done since $\overline{P} = W/t$ and $W = Fd$, where d is the distance traveled. Then

$$\overline{P} = \frac{W}{t} = \frac{Fd}{t} = F\overline{v}, \qquad \textbf{(6–17)}$$

where $\overline{v} = d/t$ is the average speed of the object.

EXAMPLE 6–15 **Power needs of a car.** Calculate the power required of a 1400-kg car under the following circumstances: (*a*) the car climbs a 10° hill (a fairly steep hill) at a steady 80 km/h; and (*b*) the car accelerates along a level road from 90 to 110 km/h in 6.0 s to pass another car. Assume the retarding force on the car is $F_R = 700\text{ N}$ throughout. See Fig. 6–29.

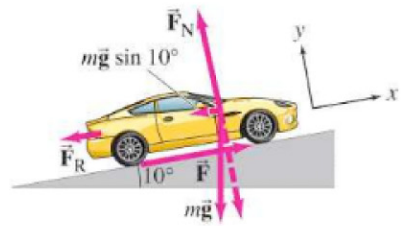

FIGURE 6–29 Example 6–15a. Calculation of power needed for a car to climb a hill.

APPROACH First we must be careful not to confuse $\vec{F}_R$, which is due to air resistance and friction that retards the motion, with the force $\vec{F}$ needed to accelerate the car, which is the frictional force exerted by the road on the tires—the reaction to the motor-driven tires pushing against the road. We must determine the latter force F before calculating the power.

SOLUTION (*a*) To move at a steady speed up the hill, the car must, by Newton's second law, exert a force F equal to the sum of the retarding force, 700 N, and the component of gravity parallel to the hill, $mg\sin 10°$. Thus

$$\begin{aligned} F &= 700\text{ N} + mg\sin 10° \\ &= 700\text{ N} + (1400\text{ kg})(9.80\text{ m/s}^2)(0.174) = 3100\text{ N}. \end{aligned}$$

Since $\overline{v} = 80\text{ km/h} = 22\text{ m/s}$ and is parallel to $\vec{F}$, then (Eq. 6–17) the power is

$$\overline{P} = F\overline{v} = (3100\text{ N})(22\text{ m/s}) = 6.80 \times 10^4\text{ W} = 91\text{ hp}.$$

(*b*) The car accelerates from 25.0 m/s to 30.6 m/s (90 to 110 km/h). Thus the car must exert a force that overcomes the 700-N retarding force plus that required to give it the acceleration

$$\overline{a}_x = \frac{(30.6\text{ m/s} - 25.0\text{ m/s})}{6.0\text{ s}} = 0.93\text{ m/s}^2.$$

We apply Newton's second law with x being the direction of motion:

$$ma_x = \Sigma F_x = F - F_R.$$

Then the force required, F, is

$$\begin{aligned} F &= ma_x + F_R \\ &= (1400\text{ kg})(0.93\text{ m/s}^2) + 700\text{ N} \\ &= 1300\text{ N} + 700\text{ N} = 2000\text{ N}. \end{aligned}$$

Since $\overline{P} = F\overline{v}$, the required power increases with speed and the motor must be able to provide a maximum power output of

$$\overline{P} = (2000\text{ N})(30.6\text{ m/s}) = 6.12 \times 10^4\text{ W} = 82\text{ hp}.$$

NOTE Even taking into account the fact that only 60 to 80% of the engine's power output reaches the wheels, it is clear from these calculations that an engine of 100 to 150 hp is quite adequate from a practical point of view.