The tension is constant along the rope, so the force $\vec{F}$ exerted by the dog on the rope equals the force $\vec{T}$ exerted by the rope on the sled (Figure 4-8). Constant tension in a string or rope also holds for a string that passes over a frictionless peg or pulley of negligible mass as long as there are no tangential forces acting on the string between the two points considered.

In this simple example, we found two things: the horizontal acceleration ($a_x = T/m = F/m$), and the vertical force F_n exerted by the ice ($F_n = w$). According to Newton's third law, forces always act in pairs. Figure 4-7 shows only those forces that act on the sled. Figure 4-9 shows the reaction forces to those in Figure 4-7. These are the gravitational force $\vec{w}'$ exerted by the sled on the earth, the force $\vec{F}'_n$ exerted by the sled *on the ice*, and the force $\vec{T}'$ exerted by the sled *on the rope*. Since these forces are not exerted on the sled, they have nothing to do with its motion. Therefore, they are not part of the application of Newton's second law to the motion of the sled.

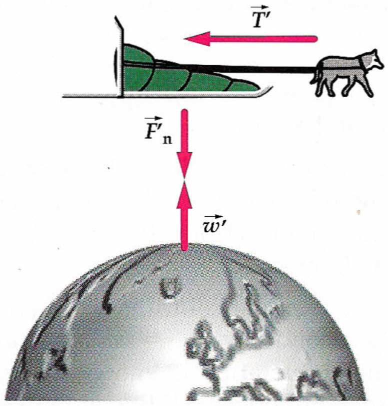


Figure 4-9 The reaction forces corresponding to the three forces shown in Figure 4-7. These forces do *not* act on the sled.

Example 4-7

During your winter break, you enter a dogsled race in which students replace the dogs. Wearing cleats for traction, you begin the race by pulling on a rope attached to the sled with a force of 150 N at 25° with the horizontal. The mass of the sled is 80 kg and there is negligible friction between the sled and ice (Figure 4-10). Find (*a*) the acceleration of the sled and (*b*) the normal force $\vec{F}_n$ exerted by the surface on the sled.

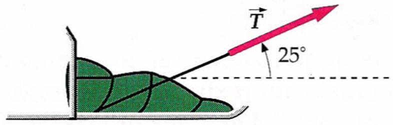
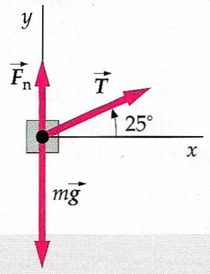


Figure 4-10

Picture the Problem Three forces act on the sled: its weight, $m\vec{g}$, which acts downward; the normal force, $\vec{F}_n$, which acts upward; and the tension in the rope, $\vec{T}$, directed 25° above the horizontal. Since the forces do not lie along a line, we study the system by applying Newton's second law to the x and y directions separately. We choose x to be in the direction of motion, and y to be perpendicular to the ice. Then we draw a free-body diagram for the sled.



(*a*) Apply $\Sigma\vec{F} = m\vec{a}$ to motion along the x axis to determine the acceleration of the sled, a_x:

$$\sum F_x = T\cos\theta = ma_x$$

$$a_x = \frac{T\cos\theta}{m} = \frac{(150\text{ N})(\cos 25°)}{80\text{ kg}} = 1.70\text{ m/s}^2$$

(*b*) There is no acceleration in the y direction. Apply $\Sigma\vec{F} = m\vec{a}$ to motion along the y axis to determine F_n:

$$\sum F_y = T\sin\theta + F_n - mg = ma_y = 0$$

$$F_n = mg - T\sin\theta$$

$$= (80\text{ kg})(9.81\text{ N/kg}) - (150\text{ N})(\sin 25°) = 721\text{ N}$$

Remarks Note that only the x component of the tension, $T\cos\theta$, causes the sled to accelerate. Also note that the ice supports less than the full weight of the sled, since part of the weight, $T\sin\theta$, is supported by the rope.

Check the Result If $\theta = 0$, the sled is accelerated by a force T and the ice supports all the weight of the sled. Our results agree, giving $a_x = T/m$ and $F_n = mg$. For $\theta = 90°$, $a_x = 0$ and $F_n = mg - T$, as expected.

Exercise What is the greatest tension that can be applied to the rope without lifting the sled off the surface? (*Answer* $T = 1.86$ kN)