9.16. MODEL: Model the bug as a particle whose increase in speed is due entirely to the wind.

VISUALIZE: We are given $m = 45$ g.

SOLVE: (a)

$$W = F \cdot \Delta r = (4.0\hat{i} - 6.0\hat{j}) \times 10^{-2}\text{ N} \cdot (2.0\hat{i} - 2.0\hat{j})\text{ m} = (0.080 + 0.12)\text{ J} = 0.20\text{ J}$$

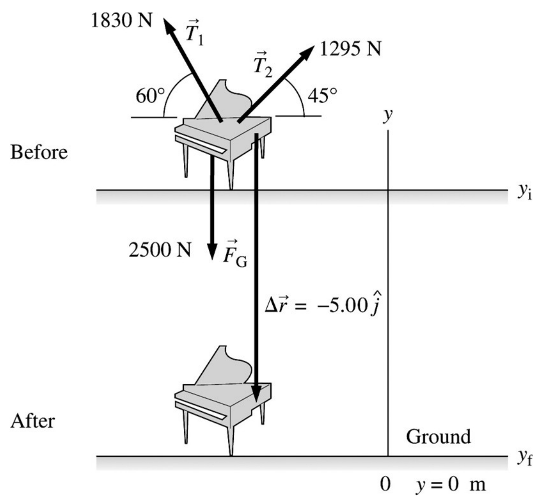
(b) Recall that $v_i = 0$ m/s.

$$W = \Delta K = \tfrac{1}{2}m(v_f^2 - v_i^2) = \tfrac{1}{2}mv_f^2 \Rightarrow v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2(0.20\text{ J})}{0.045\text{ kg}}} = 3.0\text{ m/s}$$

REVIEW: This seems like a good speed for a bug.

9.19. MODEL: Model the piano as a particle and use $W = F \cdot \Delta r$, where W is the work done by the force F through the displacement Δr.

VISUALIZE:



SOLVE: For the force F_G:

$$W = F \cdot \Delta r = F_G \cdot \Delta r = (F_g) \cdot (\Delta r)\cos(0^\circ) = (255\text{ kg})(9.81\text{ m/s}^2)(5.00\text{ m})(1.00) = 1.25 \times 10^4\text{ J}$$

For the tension T_1:

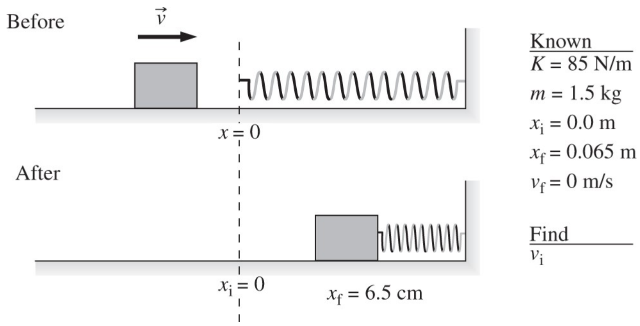
$$W = T_1 \cdot \Delta r = (T_1)(\Delta r)\cos(150^\circ) = (1830\text{ N})(5.00\text{ m})(-0.8660) = -7.92 \times 10^3\text{ J}$$

For the tension T_2:

$$W = T_2 \cdot \Delta r = (T_2)(\Delta r)\cos(135^\circ) = (1295\text{ N})(5.00\text{ m})(-0.7071) = -4.58 \times 10^3\text{ J}$$

REVIEW: Note that the displacement Δr in all the above cases is directed downward along $-\hat{j}$.

9.30. MODEL: Assume the box is a particle.



VISUALIZE: Use the energy principle. The work comes from integrating a variable force.

SOLVE:

$$\int_0^{x_f} -kx\,dx = W = \Delta K = \tfrac{1}{2}m(v_f^2 - v_i^2)$$

$$-k\left[\tfrac{1}{2}x^2\right]_0^{0.065} = \tfrac{1}{2}m(0 - v_i^2)$$

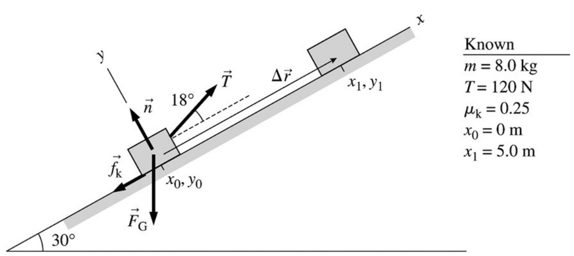
Cancel 1/2 and a negative and solve for v_i.

$$v_i = \sqrt{\frac{k}{m}(0.065\text{ m})^2} = \sqrt{\frac{(85\text{ N/m})}{1.5\text{ kg}}(0.065\text{ m})^2} = 0.49\text{ m/s}$$

REVIEW: This seems like a reasonable speed.

9.35. MODEL: Use the particle model, the definition of work $W = F \cdot \Delta s$, and the model of kinetic friction.

VISUALIZE: We place the coordinate frame on the incline so that its x-axis is along the incline.



SOLVE: (a) $W_T = T \cdot \Delta r = T\Delta x\cos(18^\circ) = (120\text{ N})(5.0\text{ m})\cos(18^\circ) = 0.57\text{ kJ}$

$$W_g = F_G \cdot \Delta r = mg\Delta x\cos(120^\circ) = (8.0\text{ kg})(9.8\text{ m/s}^2)(5.0\text{ m})\cos(120^\circ) = -0.20\text{ kJ}$$

$$W_n = n \cdot \Delta r = n\Delta x\cos(90^\circ) = 0.0\text{ J}$$

(b) The amount of energy transformed into thermal energy is $\Delta E_{th} = f_k\Delta x = \mu_k n\Delta x$.

To find n, we write Newton's second law as follows:

$$\Sigma F_y = n - F_G\cos(30^\circ) + T\sin(18^\circ) = 0\text{ N} \quad\Rightarrow\quad n = F_G\cos(30^\circ) - T\sin(18^\circ)$$

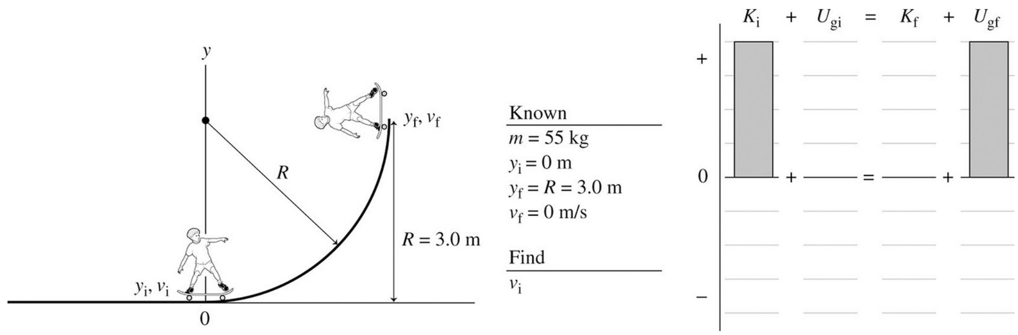
$$n = mg\cos(30^\circ) - T\sin(18^\circ) = (8.0\text{ kg})(9.8\text{ m/s}^2)\cos(30^\circ) - (120\text{ N})\sin(18^\circ) = 30.814\text{ N}$$

Thus, $\Delta E_{th} = (0.25)(30.814\text{ N})(5.0\text{ m}) = 39\text{ J}$.

REVIEW: Any force that acts perpendicular to the displacement does no work.

10.6. **MODEL:** Model the skateboarder as a particle. Assuming that the track offers no rolling friction, the sum of the skateboarder's kinetic and gravitational potential energy does not change during his rolling motion.

VISUALIZE:



The vertical displacement of the skateboarder is equal to the radius of the track.

SOLVE: The quantity $K + U_g$ is the same at the upper edge of the quarter-pipe track as it was at the bottom. The energy conservation equation $K_f + U_{gf} = K_i + U_{gi}$ is

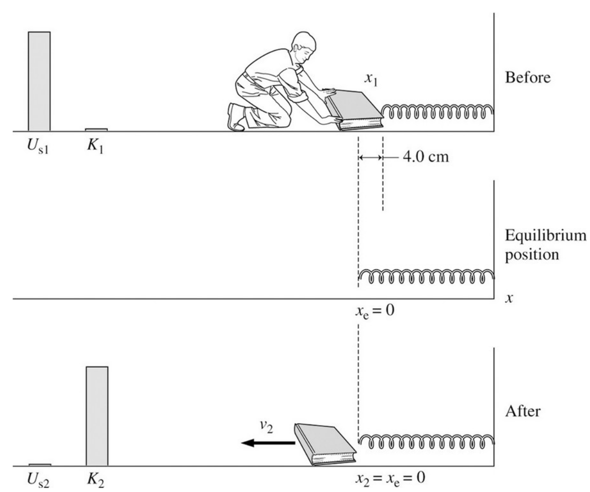
$$\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i \Rightarrow v_i^2 = v_f^2 + 2g(y_f - y_i)$$

$$v_i^2 = (0 \text{ m/s})^2 + 2(9.8 \text{ m/s}^2)(3.0 \text{ m} - 0 \text{ m}) = 58.8 \text{ m}^2/\text{s}^2 \Rightarrow v_i = 7.7 \text{ m/s}$$

REVIEW: Note that we did not need to know the skateboarder's mass, as is the case with free-fall motion.

10.16. **MODEL:** Assume an ideal spring that obeys Hooke's law. There is no friction, so the mechanical energy $K + U_s$ is conserved. Also model the book as a particle.

VISUALIZE:



The figure shows a before-and-after pictorial representation. The compressed spring will push on the book until the spring has returned to its equilibrium length. We put the origin of our coordinate system at the equilibrium position of the free end of the spring. The energy bar chart shows that the potential energy of the compressed spring is entirely transformed into the kinetic energy of the book.

SOLVE: The conservation of energy equation $K_2 + U_{s2} = K_1 + U_{s1}$ is

$$\frac{1}{2}mv_2^2 + \frac{1}{2}k(x_2 - x_e)^2 = \frac{1}{2}mv_1^2 + \frac{1}{2}k(x_1 - x_e)^2$$

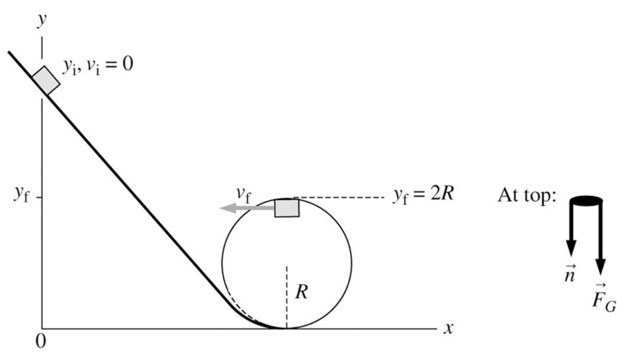
Using $x_2 = x_e = 0$ m and $v_1 = 0$ m/s, this simplifies to

$$\frac{1}{2}mv_2^2 = \frac{1}{2}k(x_1 - 0\text{ m})^2 \Rightarrow v_2 = \sqrt{\frac{kx_1^2}{m}} = \sqrt{\frac{(1250\text{ N/m})(0.040\text{ m})^2}{(0.500\text{ kg})}} = 2.0\text{ m/s}$$

REVIEW: This problem cannot be solved using constant-acceleration kinematic equations. The acceleration is not a constant in this problem, since the spring force, given as $F_s = -k\Delta x$, is directly proportional to Δx or $|x - x_e|$.

10.44. MODEL: This is a two-part problem. In the first part, we will find the critical velocity for the block to go over the top of the loop without falling off. Since there is no friction, the sum of the kinetic and gravitational potential energy is conserved during the block's motion. We will use this conservation equation in the second part to find the minimum height the block must start from to make it around the loop.

VISUALIZE:



We place the origin of our coordinate system directly below the block's starting position on the frictionless track.

SOLVE: The free-body diagram on the block implies

$$F_G + n = \frac{mv_c^2}{R}$$

For the block to just stay on track, $n = 0$. Thus the critical velocity v_c is

$$F_G = mg = \frac{mv_c^2}{R} \Rightarrow v_c^2 = gR$$

The block needs kinetic energy $\frac{1}{2}mv_c^2 = \frac{1}{2}mgR$ to go over the top of the loop. We can now use the conservation of mechanical energy equation to find the minimum height *h*.

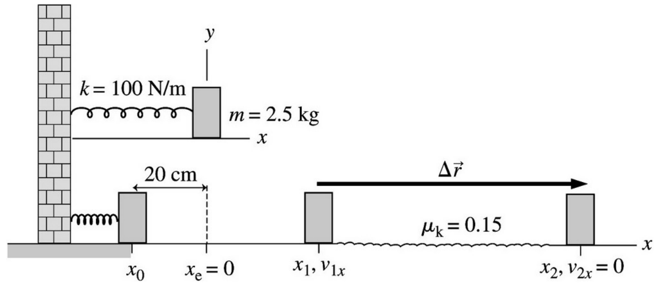
$$K_f + U_{gf} = K_i + U_{gi} \Rightarrow \frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i$$

Using $v_f = v_c = \sqrt{gR}$, $y_f = 2R$, $v_i = 0$ m/s, and $y_i = h$, we obtain

$$\frac{1}{2}gR + g(2R) = 0 + gh \Rightarrow h = 2.5R$$

10.48. Model: Assume an ideal spring that obeys Hooke's law. Model the box as a particle and use the model of kinetic friction.

VISUALIZE:



SOLVE: When the horizontal surface is frictionless, conservation of energy means

$$\tfrac{1}{2}k(x_0 - x_e)^2 = \tfrac{1}{2}mv_{1x}^2 = K_1 \quad \Rightarrow \quad K_1 = \tfrac{1}{2}(100\ \text{N/m})(0.20\ \text{m} - 0\ \text{m})^2 = 2.0\ \text{J}$$

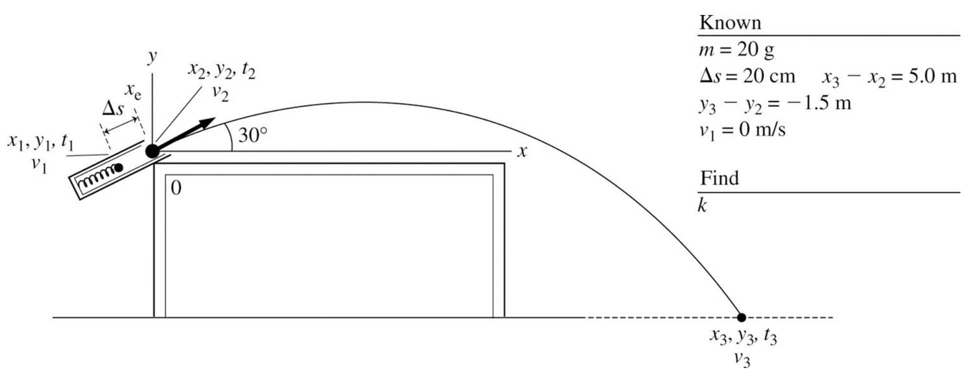
That is, the box is launched with 2.0 J of kinetic energy. 2.0 J of kinetic energy will be converted to thermal energy as it crosses the rough surface. The net force on the box is $F_{\text{net}} = -f_k = -\mu_k mg\hat{i}$. The energy principle is

$$W_{\text{net}} = F_{\text{net}} \cdot \Delta r = \Delta K + \Delta E_{\text{th}} = 0 \Rightarrow K_2 - K_1 = -\Delta E_{\text{th}} = -2.0\ \text{J}$$
$$(-\mu_k mg)(x_2 - x_1) = -2.0\ \text{J}$$
$$(x_2 - x_1) = \frac{2.0\ \text{J}}{\mu_k mg} = \frac{2.0\ \text{J}}{(0.15)(2.5\ \text{kg})(9.8\ \text{m/s}^2)} = 0.54\ \text{m}$$

REVIEW: Because the force of friction transforms kinetic energy into thermal energy, energy is transferred out of the box into the environment. In response, the box slows down and comes to rest.

10.71. MODEL: Assume an ideal spring that obeys Hooke's law. The mechanical energy $K + U_s + U_g$ is conserved during the launch of the ball.

VISUALIZE:



This is a two-part problem. In the first part, we use projectile equations to find the ball's velocity v_2 as it leaves the spring. This will yield the ball's kinetic energy as it leaves the spring.

SOLVE: Using the equations of kinematics,

$$x_3 = x_2 + v_{2x}(t_3 - t_2) + \frac{1}{2}a_x(t_3 - t_2)^2 \Rightarrow 5.0 \text{ m} = 0 \text{ m} + (v_2\cos 30°)(t_3 - 0 \text{ s}) + 0 \text{ m}$$

$$(v_2\cos 30°)t_3 = 5.0 \text{ m} \Rightarrow t_3 = (5.0 \text{ m}/v_2\cos 30°)$$

$$y_3 = y_2 + v_{2y}(t_3 - t_2) + \frac{1}{2}a_y(t_3 - t_2)^2$$

$$-1.5 \text{ m} = 0 + (v_2\sin 30°)(t_3 - 0 \text{ s}) + \frac{1}{2}(9.8 \text{ m/s}^2)(t_3 - 0 \text{ s})^2$$

Substituting the value for t_3, $(-1.5 \text{ m}) = (v_2\sin 30^\circ)\left(\dfrac{5.0 \text{ m}}{v_2\cos 30^\circ}\right) - (4.9 \text{ m/s}^2)\left(\dfrac{5.0 \text{ m}}{v_2\cos 30^\circ}\right)^2$

$$\Rightarrow (-1.5 \text{ m}) = +(2.887 \text{ m}) - \frac{163.33}{v_2^2} \Rightarrow v_2 = 6.102 \text{ m/s}$$

The conservation of energy equation $K_2 + U_{s2} + U_{g2} = K_1 + U_{s1} + U_{g1}$ is

$$\frac{1}{2}mv_2^2 + \frac{1}{2}k(0 \text{ m})^2 + mgy_2 = \frac{1}{2}mv_1^2 + \frac{1}{2}k(\Delta s)^2 + mgy_1$$

Using $y_2 = 0 \text{ m}$, $v_1 = 0 \text{ m/s}$, $\Delta s = 0.20 \text{ m}$, and $y_1 = -(\Delta s)\sin g30^\circ$, we get

$$\frac{1}{2}mv_2^2 + 0 \text{ J} + 0 \text{ J} = 0 \text{ J} + \frac{1}{2}k(\Delta s)^2 - mg(\Delta s)\sin 30^\circ \qquad (\Delta s)^2 k = mv_2^2 + 2mg(\Delta s)\sin 30^\circ$$

$$(0.20 \text{ m})^2 k = (0.020 \text{ kg})(6.102 \text{ m/s})^2 + 2(0.020 \text{ kg})(9.8 \text{ m/s}^2)(0.20)(0.5) \Rightarrow k = 19.6 \text{ N/m}$$

The final answer rounds to 20 N/m.

REVIEW: Note that $y_1 = -(\Delta s)\sin 30^\circ$ is with a minus sign and hence the gravitational potential energy mgy_1 is $-mg(\Delta s)\sin 30^\circ$.