Problems 4.37 and 4.38

Consider a 3300 lb car whose speed is increased by 35 mph over a distance of 200 ft while traveling up a rectilinear incline with a 15% grade. Model the car as a particle, assume that the tires do not slip, and neglect *all* sources of frictional losses and drag.

Figure P4.37 and P4.38

Problem 4.37 Determine the work done on the car by the engine if the car starts from rest.

Problem 4.38 Determine the work done on the car by the engine if the car has an initial speed of 30 mph.

The crates A and B of weight $W_A = 50$ lb and $W_B = 75$ lb, respectively, are connected by a pulley system. The system is released from rest and friction between A and the horizontal surface is insufficient to prevent slipping. The cables in the pulley system are inextensible, and the coefficient of kinetic friction between the crate A and the horizontal surface is μ_k.

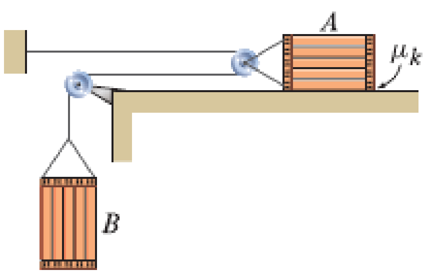

Figure P4.78–P4.80

Problem 4.78 If $\mu_k = 0$, determine the speed of B after A slides 10 ft.

Problem 4.79 Determine the required value of μ_k so that the speed of B is 27 ft/s after it drops 15 ft.

Problem 4.86

Two identical balls, each of mass m, are connected by a string of negligible mass and length $2l$. A short string is attached to the first at its middle and is pulled vertically with a constant force P (exerted by the hand). If the system starts at rest when $\theta = \theta_0$, determine the speed of the two balls as θ approaches 90°. Neglect the size of the balls as well as friction between the balls and the surface on which they slide.

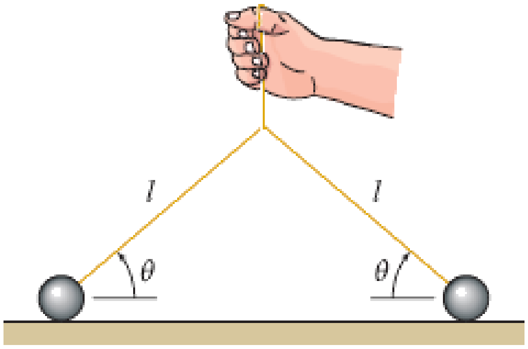

Figure P4.86

Problems 5.94 and 5.95

Ball B is stationary when it is hit by an identical ball A as shown, with $\beta = 45°$. The preimpact speed of ball A is $v_0 = 1$ m/s.

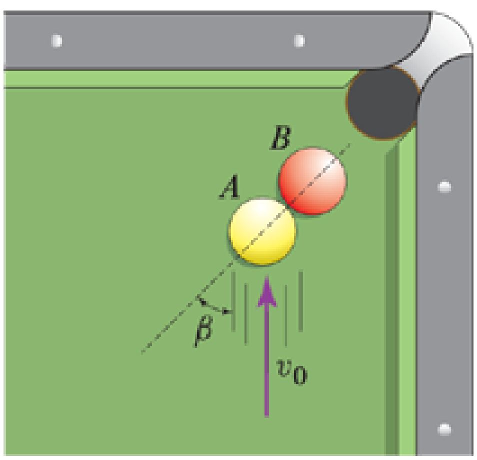

Figure P5.94 and P5.95

Problem 5.94 Determine the postimpact velocity of ball B if the COR of the collision $e = 1$.

Problem 5.95 Determine the postimpact velocity of ball A if the COR of the collision $e = 0.8$.

Problems 5.99 and 5.100

Two spheres, A and B, with masses m_A = 1.35 kg and m_B = 2.72 kg, respectively, collide with v_A^- = 26.2 m/s, and v_B^- = 22.5 m/s.

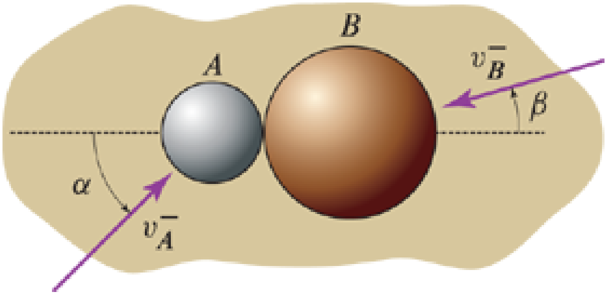

Figure P5.99 and P5.100

Problem 5.99 Compute the postimpact velocities of A and B if α = 45°, β = 16°, the COR is e = 0.57, and the contact between A and B is frictionless.

Problem 5.100 Compute the postimpact velocities of A and B if α = 45°, β = 16°, the COR is e = 0, and the contact between A and B is frictionless.

Problem 5.68

A 323 gr bullet B (1 lb = 7000 gr) moving at v_0 = 800 ft/s hits a 4 lb block A that is initially at rest. The block is attached to an uncompressed spring of stiffness k = 6000 lb/ft. After the collision, the bullet becomes embedded in the block. Neglecting friction between the block and the surface on which it slides, determine the compression of the spring required to bring the system to a stop.

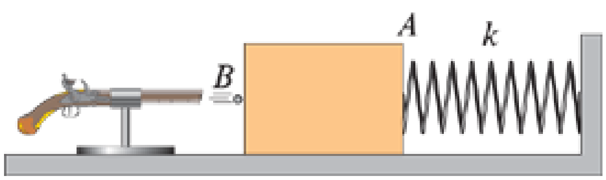

Figure P5.68

Problem 6.48

A truck is moving to the right with a speed v_0 = 12 km/h, while the pipe section with radius R = 1.25 m and center at C rolls without slipping over the truck's bed. The center of the pipe section C is moving to the right at 2 m/s relative to the truck. Determine the angular velocity of the pipe section and the absolute velocity of C.

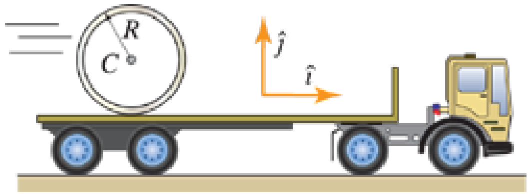

Figure P6.48

Problem 6.49

A wheel W of radius R_W = 7 mm is connected to point O via the rotating arm OC, and it rolls without slip over the stationary cylinder S of radius R_S = 15 mm. If, at the instant shown, θ = 47° and ω_{OC} = 3.5 rad/s, determine the angular velocity of the wheel and the velocity of point Q, where point Q lies on the edge of W and along the extension of the line OC.

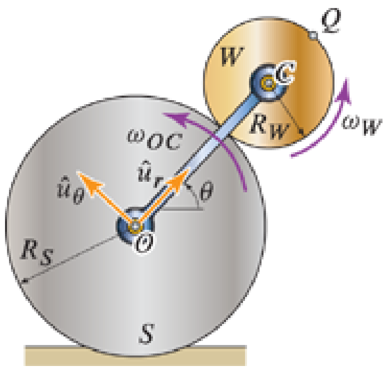

Figure P6.49

The wheel W of radius R = 1.4 m rolls without slip on a horizontal surface. A bar AB of length L = 3.7 m is pin-connected to the center of the wheel and to a slider A constrained to move along a vertical guide. Point C is the bar's midpoint.

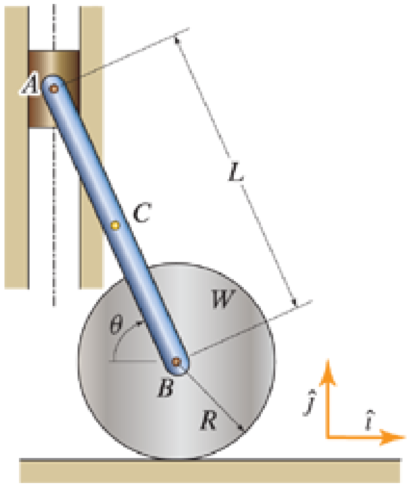

Figure P6.112–P6.114

Problem 6.112 If the wheel is rolling clockwise with a constant angular speed of 2 rad/s, determine the angular acceleration of the bar when θ = 72°.

Problem 6.113 If the slider A is moving downward with a constant speed 3 m/s, determine the angular acceleration of the wheel when θ = 53°.

For the slider-crank mechanism shown, let R = 0.75 m and H = 2 m, and let the length of bar BC be L_{BC} = 3.25 m.

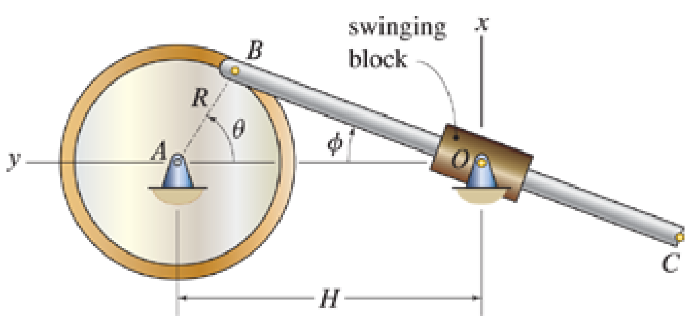

Figure P6.116–P6.119

Problem 6.116 Assume that $\dot{\theta} = 50\,\text{rad/s} = \text{constant}$ and compute the angular acceleration of the slider for θ = 27°.

Problem 6.117 Assume that, at the instant shown, θ = 27°, $\dot{\theta} = 50\,\text{rad/s}$, and $\ddot{\theta} = 15\,\text{rad/s}^2$. Compute the angular acceleration of the slider at this instant, as well as the acceleration of point C.

Problem 6.150 For the position shown, determine

a. The angular velocity of the slotted arm *CD* and the velocity of the bar

b. The angular acceleration of the slotted arm *CD* and the acceleration of the bar

Evaluate your results for ω_{AB} = 120 rpm, R/h = 0.5, and d = 0.12 m.

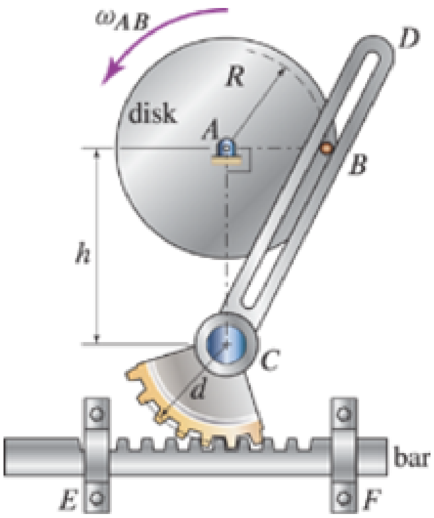

Figure P6.150

Problem 6.158

A floodgate is controlled by the motion of the hydraulic cylinder *AB*. If the gate *BC* is to be lifted with a constant angular velocity ω_{BC} = 0.5 rad/s, determine $\dot{d}_{AB}$ and $\ddot{d}_{AB}$, where d_{AB} is the distance between points *A* and *B* when ϕ = 0. Let ℓ = 10 ft, h = 2.5 ft, and d = 5 ft.

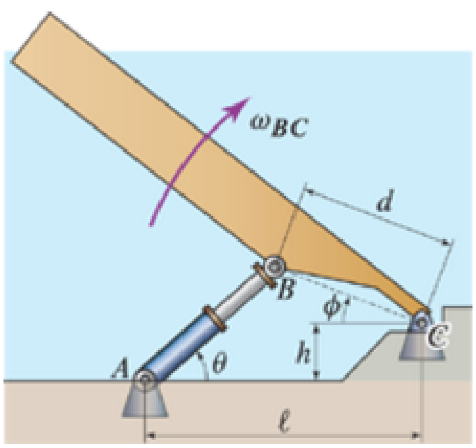

Figure P6.158

Example 4.14

EXAMPLE 4.14 *Internal Work Due to Friction*

The two blocks *A* and *B* of mass m_A = 4 kg and m_B = 1 kg, respectively, in Fig. 1 are connected by an inextensible cord and the pulley system shown. There is negligible friction between *A* and the θ = 30° incline, and the coefficient of kinetic friction between *A* and *B* is μ_k = 0.1. Assuming that μ_s is insufficient to prevent slipping and that the system is released from rest, determine the velocity of *A* and *B* after *B* has moved *up the incline* a distance *d* = 0.35 m *relative to A*.

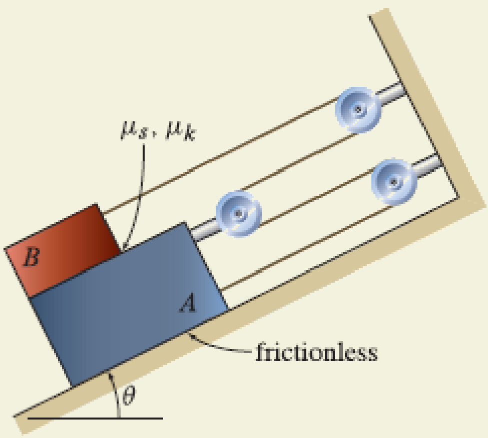

Figure 1 The two-block system connected by pulleys.

SOLUTION

Road Map & Modeling Since we need to relate changes in position to changes in velocity, we will apply the work-energy principle. In Fig. 2, we have sketched the system's FBD, which includes *A* and *B* modeled as particles, the cord, and the pulleys. We ignore friction in the pulleys and assume the cord is inextensible and has negligible mass. The cord tension does no work because the cord is inextensible. However, since *A* and *B* slide relative to one another, we need to include the work done by the internal friction force between *A* and *B*, so we have also drawn the FBD of *B* in Fig. 2 so that we can find this friction force. Finally, we will let ① be when the system is released and ② be when *B* has moved the distance *d* up the incline relative to *A*.

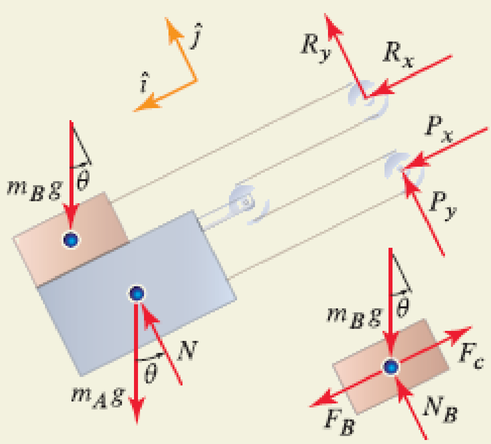

Figure 2 FBD of the system and of just *B*.

Governing Equations

Balance Principles The work-energy principle for the system in Fig. 2 is

$$T_1 + V_1 + (U_{1\text{-}2})^{\text{int}}_{\text{nc}} = T_2 + V_2, \tag{1}$$

where $(U_{1-2})_{nc}^{int}$ is the work done by friction. The kinetic energies are given by

$$T_1 = \tfrac{1}{2}m_A v_{A1}^2 + \tfrac{1}{2}m_B v_{B1}^2 \quad \text{and} \quad T_2 = \tfrac{1}{2}m_A v_{A2}^2 + \tfrac{1}{2}m_B v_{B2}^2, \tag{2}$$

where v_A and v_B are the speed of A and B, respectively, and the second subscript on the speeds indicates position. Again referring to Fig. 2, we sum forces in the y direction on B and obtain

$$\sum F_y: \quad N_B - m_B g \cos\theta = 0, \tag{3}$$

where we have set $a_{By} = 0$ because there is no motion in the y direction.

Force Laws For the system's potential energy we can write

$$V_1 = V_{A1} + V_{B1} = 0, \tag{4}$$

$$V_2 = V_{A2} + V_{B2} = -m_A g\, \Delta x_A \sin\theta - m_B g\, \Delta x_B \sin\theta, \tag{5}$$

where we have placed the datum for the potential energy at ① and where Δx_A and Δx_B are the displacements parallel to the incline of A and B, respectively, between ① and ②. Both Δx_A and Δx_B are unknown, and we will use kinematics to relate them to the given distance d.

The work of the internal friction force F_B is given by

$$(U_{1\text{-}2})^{\text{int}}_{\text{nc}} = -\int_0^d F_B\, dx. \tag{6}$$

Finally, since we know that μ_s is insufficient to prevent slipping, we know that

$$F_B = \mu_k N_B. \tag{7}$$

Kinematic Equations Since the system starts from rest, we have

$$v_{A1} = 0 \quad \text{and} \quad v_{B1} = 0. \tag{8}$$

In addition, we can relate the motions of A and B using pulley kinematics (see Section 2.7 on p. 121). Referring to Fig. 3, we see that for arbitrary x_A and x_B

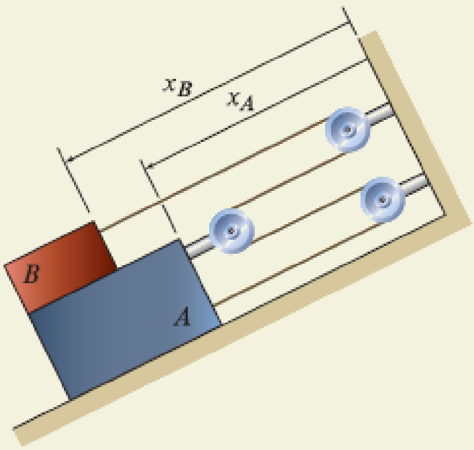

Figure 3 Definition of x_A and x_B for the two blocks.

$$3x_A + x_B = L \quad \Rightarrow \quad 3v_A = -v_B, \tag{9}$$

where L is constant and where v_A and v_B represent the velocity of A and B, respectively, since the motion is one-dimensional. From Eq. (9), at ② we have

$$3v_{A2} = -v_{B2} \quad \text{and} \quad 3\Delta x_A = -\Delta x_B. \tag{10}$$

Finally, we know that A displaces a distance d relative to B. Therefore, we can write

$$\Delta x_{A/B} = d = \Delta x_A - \Delta x_B. \tag{11}$$

Solving Eqs. (10) and (11) for Δx_A and Δx_B, we obtain

$$\Delta x_A = \tfrac{1}{4}d \quad \text{and} \quad \Delta x_B = -\tfrac{3}{4}d. \tag{12}$$

Computation Substituting Eqs. (3) and (7) into Eq. (6), we have

$$(U_{1\text{-}2})_{\text{nc}}^{\text{int}} = -\mu_k m_B g d \cos\theta. \tag{13}$$

Next, we substitute the first of Eqs. (10) into Eq. (2) to obtain

$$T_2 = \tfrac{1}{2}m_A v_{A2}^2 + \tfrac{1}{2}m_B(-3v_{A2})^2 = \tfrac{1}{2}(m_A + 9m_B)v_{A2}^2, \tag{14}$$

and then substitute Eqs. (12) into Eq. (5) to obtain

$$V_2 = \tfrac{1}{4}(3m_B - m_A)gd\sin\theta. \tag{15}$$

We then take Eqs. (4), (8), and (13)–(15) and substitute them into Eq. (1) to obtain one equation for v_{A2}

$$-\mu_k m_B g d \cos\theta = \tfrac{1}{2}(m_A + 9m_B)v_{A2}^2 + \tfrac{1}{4}(3m_B - m_A)gd\sin\theta, \tag{16}$$

which gives

$$v_{A2} = \pm\sqrt{\frac{2gd}{m_A + 9m_B}\left[\tfrac{1}{4}(m_A - 3m_B)\sin\theta - \mu_k m_B \cos\theta\right]}. \tag{17}$$

Observing that A moves down the incline and B moves up the incline, using Eqs. (17) and (9), as well as the given data, we have

$$\boxed{v_{A2} = 0.1424\,\mathrm{m/s} \quad \text{and} \quad v_{B2} = -0.4273\,\mathrm{m/s}.} \tag{18}$$

Helpful Information

What do the ± signs on Eq. (17) mean? In this example we need to determine a *velocity*. Since the motion is one-dimensional, the velocity we are seeking can be equal to the speed or opposite to the speed. The ± sign in Eq. (17) is there to remind us that we need to determine the sign of the velocity.

Discussion & Verification The dimensions of the argument of the square root in Eq. (17) are energy divided by mass, i.e., speed squared. Hence, the expression for v_{A2} in Eq. (17) is dimensionally correct. The expression of v_B in Eqs. (9) is also dimensionally correct. As far as the values in Eqs. (18) are concerned, since B acts as a counterweight for A, a way to check the reasonableness of our result is to compute the speed that A would have if it were disconnected from B and moved a distance $d/4$ down the incline without friction. This speed, given by $(v_{A2})_{\text{no friction}} = \sqrt{2(d/4)g\sin\theta} = 0.9265\,\mathrm{m/s}$, is an upper bound for v_{A2}. That is, v_{A2} must be less than 0.9265 m/s, as indeed it is.