Further Application of Newton's Laws

Friction, Drag, and Elasticity

Chapter 5

2024

Contents

Problem 10: Snowboarder Deceleration

Problem

Calculate the deceleration of a snow boarder going up a 5.0° slope assuming the coefficient of friction for waxed wood on wet snow is $\mu_k = 0.100$.

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Problem 10: Solution Steps

1. Draw the free body diagram
   - Forces: Weight ($w = mg$), Normal force (N), Friction force (f)
2. Apply Newton's Laws:
   - net $F_x = w_x + f = ma$
   - net $F_y = N - w_y = 0$
3. Given values:
   - $\theta = 5^\circ$
   - $\mu_k = 0.100$

Problem 10: Solution Steps (continued)

4. Using trigonometry:
   - $w_x = w \sin\theta = mg \sin\theta$
   - $w_y = w \cos\theta = mg \cos\theta$
   - $f = \mu_k N = \mu_k mg \cos\theta$
5. Solve for acceleration:

$$a = \frac{w_x + f}{m} = \frac{mg \sin\theta + \mu_k mg \cos\theta}{m} = g(\sin\theta + \mu_k \cos\theta)$$

6. Final calculation:

$$a = (9.80 \text{ m/s}^2)(\sin 5^\circ + (0.100) \cos 5^\circ) = 1.83 \text{ m/s}^2$$

Problem 25: Rain Drop Velocity

Problem

Calculate the velocity a spherical rain drop would achieve falling from 5.00 km:

(a) in the absence of air drag

(b) with air drag

Given:

- Drop size: 4 mm
- Density: 1.00×10^3 kg/m^3
- Cross-section area: πr^2

Problem 25: Solution (Part a)

Without air drag:

1. Use free fall equation: $v = \sqrt{2ax}$
2. Substitute values:

$$v = \sqrt{2(9.80\ \text{m/s}^2)(5000\ \text{m})} = 313\ \text{m/s}$$

Problem 25: Solution (Part b)

With air drag:

1. Calculate mass of raindrop:
   - Volume $= \frac{4}{3}\pi r^3$
   - $m = \rho V = 1000\ \text{kg/m}^3 \times \frac{4}{3}\pi(2 \times 10^{-3}\ \text{m})^3$
   - $m = 3.351 \times 10^{-5}\ \text{kg}$
2. Terminal velocity equation:

$$v_t = \sqrt{\frac{2mg}{\rho C A}}$$

   where:
   - $\rho = 1.21\ \text{kg/m}^3$ (air density)
   - $C = 0.45$ (drag coefficient)
   - $A = \pi r^2 = \pi(0.002\ \text{m})^2$

Problem 25: Final Calculation

Substituting values into terminal velocity equation:

$$v_t = \sqrt{\frac{2(3.351 \times 10^{-5}\ \text{kg})(9.80\ \text{m/s}^2)}{(1.21\ \text{kg/m}^3)(0.45)\pi(0.002\ \text{m})^2}} = 9.80\ \text{m/s}$$

Problem 30: Wrestler's Arm Bone Compression

Problem

During a wrestling match, a 150 kg wrestler briefly stands on one hand. Calculate the shortening of the upper arm bone.

Given:

- Bone length: 38.0 cm
- Bone radius: 2.10 cm
- Young's modulus (bone): 9×10^9 N/m^2

Problem 30: Solution

1. Compression equation:

$$\Delta L = \frac{1}{Y}\frac{F}{A}L_0$$

   where:
   - Y = Young's modulus = 9×10^9 N/m^2
   - F = Force = mg = (150 kg)(9.80 m/s^2)
   - A = Cross-sectional area = $\pi r^2 = \pi(0.0210\ \text{m})^2$
   - L_0 = Original length = 0.380 m

2. Final calculation:

$$\Delta L = 4.5 \times 10^{-5}\ \text{m}$$