

Further Application of Newton's Laws

Friction, Drag, and Elasticity

Chapter 5

2024

Contents

- 5.1 Friction
- 5.2 Drag Forces
- 5.3 Elasticity: Stress and Strain

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 $\mu_k = 0.100$.

CH5/Screenshot 2024-10-29 103504.png

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: $1.00 \times 10^3 \text{ kg/m}^3$
- 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:

$$v_t = \sqrt{\frac{2mg}{\rho CA}}$$

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): $9 \times 10^9 \text{ N/m}^2$

Problem 30: Solution

- ① Compression equation:

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

where:

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

- ② Final calculation:

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