PHYS12 CH: 5.1, 5.2, and 5.3

Further Applications of Newton's Laws

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September 17, 2025

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- **Drag Forces**: Introducing forces that depend on velocity ($F_D \propto v^2$).
- **Elasticity**: A deeper look at material properties using Stress and Strain.
- **Terminal Velocity**: The concept of a maximum speed in freefall when drag balances gravity.

Key Concepts: Friction

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  Static Friction (f_s) Acts on stationary objects. It is a responsive force that matches the applied force up to a maximum value.

  Kinetic Friction (f_k) Acts on moving objects. It is generally a constant value for a given speed and is less than the maximum static friction.

Essential Equations: Friction

Static Friction

The magnitude of static friction f_s can have any value up to a maximum:

$$f_s \leq \mu_s N$$

where μ_s is the coefficient of static friction and N is the normal force. Motion begins when the applied force exceeds $f_{s(\text{max})} = \mu_s N$.

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Kinetic Friction

Once an object is moving, the friction force is kinetic friction:

$$f_k = \mu_k N$$

where μ_k is the coefficient of kinetic friction. Typically, $\mu_k < \mu_s$.

Life Lesson: The Threshold of Getting Started

The Physics of Procrastination

The relationship $\mu_k < \mu_s$ teaches us a profound lesson about human behavior:

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Application to Life

Just like objects in motion tend to stay in motion, people in motion tend to stay in motion. The key is applying enough initial force to overcome static friction – then let momentum carry you forward!

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- The next slide shows a visual representation of this idea.

Concept Visualization: Microscopic Friction

[Diagram based on Figure 5.2]

A magnified view of two surfaces in contact.

- The surfaces are shown with rough, jagged profiles, even if they seem smooth macroscopically.
- The actual points of contact are only at the tips of the highest "peaks".
- When a horizontal force is applied, these peaks must either be broken off or lifted over each other for motion to occur.
- A larger normal force (N) pushes the surfaces together, increasing the contact area and the force required to move them.

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- This means drag increases significantly as an object speeds up.

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- At this point, $F_{net} = 0$, so acceleration is zero. The object stops accelerating and falls at a constant velocity called terminal velocity (v_t).

Essential Equations: Drag Force

Drag Force Equation

For many objects (cars, baseballs, skydivers), the drag force is given by:

$$F_D = \frac{1}{2} C \rho A v^2$$

- C: Drag coefficient (a dimensionless number based on shape)
- ρ: Density of the fluid (e.g., air $\approx 1.21 \text{ kg/m}^3$)
- A: Cross-sectional area of the object facing the fluid
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Terminal Velocity Equation

By setting $F_D = mg$ and solving for v, we get terminal velocity:

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

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For small deformations, most materials obey **Hooke's Law**: Stress is proportional to Strain.

Essential Equations: Elasticity

Hooke's Law

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A material property that measures stiffness in response to tension or compression. It is the ratio of stress to strain.

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This can be rearranged to find the change in length:

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

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- The next slide visualizes this relationship.

Concept Visualization: Stress-Strain Curve

[Graph based on Figure 5.11: Deformation vs. Applied Force]

A graph with Deformation (ΔL) on the y-axis and Applied Force (F) on the x-axis.

- **Linear Region**: The graph starts as a straight line from the origin. In this region, Hooke's law is obeyed. The material is elastic.

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- **Fracture Point**: The graph ends abruptly where the material breaks.

"I Do": Skiing Exercise (Friction)

Problem (Example 5.1)

A skier with a mass of 62 kg is sliding down a snowy slope angled at 25°. The force of kinetic friction resisting their motion is known to be 45.0 N.

Find the coefficient of kinetic friction, μ_k, between the skis and the snow.

[Free-body diagram of skier on an incline]

"I Do": Skiing Exercise - G & U

G - Givens

- Mass, $m = 62$ kg
- Angle, $\theta = 25^\circ$
- Kinetic friction force, $f_k = 45.0$ N
- Acceleration due to gravity, $g = 9.80$ m/s^2

U - Unknown

- Coefficient of kinetic friction, $\mu_k = ?$

E - Equation

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E - Equation

- Start with the definition of kinetic friction: $f_k = \mu_k N$.
- The normal force N on an incline balances the perpendicular component of weight: $N = w_\perp = mg\cos\theta$.
- Substitute for N: $f_k = \mu_k(mg\cos\theta)$.

"I Do": Skiing Exercise - E

E - **Equation**

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- The normal force N on an incline balances the perpendicular component of weight: $N = w_\perp = mg\cos\theta$.
- Substitute for N: $f_k = \mu_k(mg\cos\theta)$.
- **Rearrange** for the unknown, μ_k:

$$\mu_k = \frac{f_k}{mg\cos\theta}$$

"I Do": Skiing Exercise - S & S

S - Substitute

- Plug in the known values with their units:

$$\mu_k = \frac{45.0 \text{ N}}{(62 \text{ kg})(9.80 \text{ m/s}^2)\cos(25^\circ)}$$

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$$\mu_k = \frac{45.0\ \text{N}}{(62\ \text{kg})(9.80\ \text{m/s}^2)\cos(25^\circ)}$$

S - Solve

- Calculate the denominator: $(62)(9.80)(0.9063) \approx 550.5$ N.
- $\mu_k = \frac{45.0}{550.5} \approx 0.08174$
- Apply significant figures (3 sig figs from 45.0 N and 62 kg):
- $\boxed{\mu_k = 0.082}$

"We Do": Terminal Velocity (Drag)

Problem (Example 5.2)

Find the terminal velocity of an 85-kg skydiver falling in a spread-eagle position.

Estimate the frontal area as $A = 0.70\ \text{m}^2$, the drag coefficient as $C = 1.0$, and use the density of air $\rho = 1.21\ \text{kg/m}^3$.

"We Do": Terminal Velocity - G & U

G - Givens

- $m = 85$ kg
- $A = 0.70$ m^2
- $C = 1.0$
- $\rho = 1.21$ kg/m^3
- $g = 9.80$ m/s^2

U - Unknown

- Terminal velocity, $v_t = ?$

"We Do": Terminal Velocity - E

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- What is our starting equation for terminal velocity?

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- Is any algebraic rearrangement needed? (No)
- Now, let's get ready to substitute our values.

S - Substitute

- Let's plug in the numbers together:

$$v_t = \sqrt{\frac{2(85\ \text{kg})(9.80\ \text{m/s}^2)}{(1.0)(1.21\ \text{kg/m}^3)(0.70\ \text{m}^2)}}$$

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S - Solve

- Calculate the value inside the square root. What do you get?
- Numerator: $2 \times 85 \times 9.80 = 1666$
- Denominator: $1.0 \times 1.21 \times 0.70 \approx 0.847$

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- Numerator: $2 \times 85 \times 9.80 = 1666$
- Denominator: $1.0 \times 1.21 \times 0.70 \approx 0.847$
- $v_t = \sqrt{\frac{1666}{0.847}} = \sqrt{1967} \approx 44.35\ \text{m/s}$
- $\boxed{v_t \approx 44\ \text{m/s}}$

"You Do": Bone Compression (Elasticity)

Problem (Example 5.4)

Calculate the change in length of the upper leg bone (femur) when a 70.0 kg man supports 62.0 kg of his mass on it.

- **Givens**:
- Mass supported, $m = 62.0$ kg
- Original length, $L_0 = 40.0$ cm $= 0.400$ m
- Radius, $r = 2.00$ cm $= 0.0200$ m
- Young's modulus (bone compression), $Y = 9 \times 10^9$ N/m^2

Use the GUESS method to find the amount the bone shortens, ΔL.

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  - Shear Modulus and Bulk Modulus concepts.

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- The concepts discussed in these sections are important for a full understanding and may appear on assessments.

Summary

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- These concepts provide more realistic models for applying Newton's Laws to complex, everyday situations.