PHYS12 CH: 4.1-4.4, 4.6, 4.7

Force, Mass, and Defining the System

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- Draw and use **Free-Body Diagrams (FBDs)** to solve problems.
- Apply Newton's laws to solve problems for both single objects and multi-body systems.

From Physics 11 to Physics 12

Review from Physics 11

- Newton's Laws for a **single object**.
- Drawing a Free-Body Diagram for one object.
- Identifying forces like gravity ($\vec{w}$), normal force ($\vec{N}$), and tension ($\vec{T}$).
- Solving for acceleration or force on one object using $\sum \vec{F} = m\vec{a}$.

New in Physics 12

- Applying Newton's Laws to **systems of multiple objects**.
- Strategically choosing the "system of interest" to simplify problems.
- Understanding how internal forces cancel out within a system.
- Solving for forces between connected objects.

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  - $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$
- Forces are added together using vector addition to find the **net force** ($\vec{F}_{net}$).

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- We draw vector arrows representing all **external forces** acting *on* the system.
- We do **not** draw internal forces or forces exerted *by* the system.
- The FBD is the most critical first step for solving almost any dynamics problem.

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- We will use the example of two ice skaters pushing a third skater from Figure 4.3 in your textbook.
- The two pushes ($\vec{F}_1$ and $\vec{F}_2$) are individual external forces. The **net force** ($\vec{F}_{tot}$) is their vector sum, which determines the direction of acceleration.

Visualization: Adding Forces on an FBD

[Diagram based on Figure 4.3]

Physical Situation:

- An overhead view shows two skaters applying forces $\vec{F}_1$ and $\vec{F}_2$ to a third skater.

[Image of two skaters pushing a third skater]

Free-Body Diagram:

- The third skater is a dot.
- $\vec{F}_1$ and $\vec{F}_2$ are drawn tail-to-dot.
- The resultant vector $\vec{F}_{tot}$ shows the net force.

[FBD showing two force vectors from a point]

Newton's First Law: The Law of Inertia

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- **Inertia** is the property of an object to resist changes in its state of motion.
- **Mass (m)** is the quantitative measure of inertia. More mass means more inertia.

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- CRITICAL POINT: The two forces in an action-reaction pair always act on **different objects**.
    - Therefore, they **never** cancel each other out when analyzing the motion of a single object.

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- Let's visualize how action-reaction pairs work. The key is to see that the forces act on different systems.
- We will look at a swimmer pushing off the wall of a pool (based on Figure 4.9).
- The "action" is the swimmer pushing on the wall.
- The "reaction" is the wall pushing on the swimmer. Only the reaction force affects the swimmer's motion.

Visualization: Swimmer at the Wall

[Diagram based on Figure 4.9]

- **Force 1 (Action):** The swimmer's feet exert a force $\vec{F}_{feet\_on\_wall}$ on the wall. This force acts ON THE WALL.

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- **Force 2 (Reaction):** The wall exerts an equal and opposite force $\vec{F}_{wall\_on\_feet}$ on the swimmer. This force acts ON THE SWIMMER.
- The swimmer accelerates because the net external force on *her* (from the wall) is not zero.

[Image showing swimmer pushing off a wall, with force vectors on both swimmer and wall]

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- **External forces** act on the system from the outside.
  - These are the forces that cause the system to accelerate.
  - They are the only forces shown on an FBD of the system.
- **Internal forces** are forces that objects within the system exert on each other.
  - These forces always come in action-reaction pairs and cancel out, so they **do not affect the system's overall acceleration**.

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- Let's see how changing the system changes which forces are external.
- We'll use the example of a professor pushing a cart from Figure 4.10.

Visualization: Professor and Cart Systems

[Diagram based on Figure 4.10]

System 1: (Professor + Cart)

- External forces: Force from floor on feet, friction.
- Internal force: Professor pushing cart, cart pushing professor. These cancel.

System 2: (Cart Only)

- External forces: Force from professor on cart, friction.
- No internal forces to consider.

[Image showing a professor pushing a cart, with boxes drawn around "System 1" and "System 2"]

Newton's Second Law: The Law of Acceleration

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- "The acceleration of a system is directly proportional to and in the same direction as the **net external force** acting on the system, and is inversely proportional to its total mass."
- This is the central, quantitative law of dynamics. It connects force, mass, and motion.

Essential Equations

Newton's Second Law

$$\vec{F}_{net} = m\vec{a}$$

- $\vec{F}_{net}$ is the vector sum of all *external* forces on the system.
- m is the total mass of the system.
- $\vec{a}$ is the acceleration of the system.

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Weight (Force of Gravity)

$$\vec{w} = m\vec{g}$$

- $\vec{w}$ is the force of gravity on an object.
- m is the object's mass.
- $\vec{g}$ is the acceleration due to gravity (approx. 9.8 m/s^2 down on Earth).

I Do: Getting up to Speed (Example 4.3)

Problem

A professor (65.0 kg) pushes a cart (12.0 kg) with equipment (7.0 kg). She exerts a 150 N backward force on the floor. All forces opposing the motion total 24.0 N. Calculate the acceleration.

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System of Interest

For this question, our system is the **professor + cart + equipment** because we want the acceleration of everything together.

I Do: GUESS Method (G & U)

G - Givens

- $m_{prof} = 65.0$ kg
- $m_{cart} = 12.0$ kg
- $m_{equip} = 7.0$ kg
- Force on floor $= 150$ N
- $\implies F_{floor\_on\_prof} = 150$ N [forward]
- $f = 24.0$ N [backward]

U - Unknown

- Acceleration, $a = ?$

I Do: GUESS Method (E)

E - Equation

- Start with Newton's Second Law for the whole system:

$$F_{net} = m_{total} a$$

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E - Equation

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- The net external force is the forward force from the floor minus the backward friction:

$$F_{net} = F_{floor\_on\_prof} - f$$

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- The total mass is the sum of all parts:

$$m_{total} = m_{prof} + m_{cart} + m_{equip}$$

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- Rearrange for the unknown, a:

$$a = \frac{F_{net}}{m_{total}} = \frac{F_{floor\_on\_prof} - f}{m_{prof} + m_{cart} + m_{equip}}$$

I Do: GUESS Method (S & S)

S - Substitute

- First, calculate total mass:

$$m_{total} = 65.0 + 12.0 + 7.0 = 84.0 \text{ kg}$$

- Now substitute into the acceleration equation:

$$a = \frac{150 \text{ N} - 24.0 \text{ N}}{84.0 \text{ kg}}$$

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S - Solve

- Calculate the final value:

$$a = \frac{126 \text{ N}}{84.0 \text{ kg}} = 1.5 \text{ m/s}^2$$

- $\boxed{a = 1.5 \text{ m/s}^2 \text{ [forward]}}$

We Do: Force on the Cart (Example 4.4)

Problem

Using the data from the previous problem, calculate the force the professor exerts on the cart.

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New System of Interest

Now, our system must be the **cart + equipment** because the force from the professor is an *external force* on this new system.

We Do: GUESS Method (G & U)

G - Givens

- $m_{cart} = 12.0$ kg
- $m_{equip} = 7.0$ kg
- $m_{sys2} = 19.0$ kg
- $a = 1.5$ m/s^2 (from "I do")
- $f_{total} = 24.0$ N (The problem states this friction applies to cart wheels and air resistance, so it acts on the cart system).

U - Unknown

- Force from professor on cart, $F_{prof} = ?$

We Do: GUESS Method (E)

E - Equation

- Apply Newton's Second Law to our new system (the cart + equipment):

$$F_{net} = m_{sys2}a$$

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- **Question:** What forces make up F_{net} for this system?
    - *Answer: The forward push from the professor (F_{prof}) and the backward friction (f).*

$$F_{prof} - f = m_{sys2}a$$

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- Apply Newton's Second Law to our new system (the cart + equipment):

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- **Question:** What forces make up F_{net} for this system?
  - *Answer: The forward push from the professor (F_{prof}) and the backward friction (f).*

$$F_{prof} - f = m_{sys2} a$$

- **Question:** How do we rearrange for the unknown, F_{prof}?
  - *Answer: Add friction f to both sides.*

$$F_{prof} = m_{sys2} a + f$$

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- **Question:** What values should we use for m_{sys2}, a, and f?
  - $m_{sys2} = 19.0$ kg
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$$F_{prof} = (19.0 \text{ kg})(1.5 \text{ m/s}^2) + 24.0 \text{ N}$$

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S - Solve

- Let's calculate the result.

$$F_{prof} = 28.5 \text{ N} + 24.0 \text{ N} = 52.5 \text{ N}$$

- $\boxed{F_{prof} = 53 \text{ N}}$

You Do: Drag Force on a Barge (Example 4.7)

Problem

Two tugboats push on a barge. Tugboat 1 exerts a force of 2.7×10^5 N in the x-direction. Tugboat 2 exerts a force of 3.6×10^5 N in the y-direction. The mass of the barge is 5.0×10^6 kg and its acceleration is observed to be 7.5×10^{-2} m/s^2 in the direction of the net applied force from the tugboats.

What is the drag force of the water on the barge resisting the motion?

Hint

1. Find the magnitude and direction of the total applied force from the tugboats. 2. Calculate the net force needed to cause the observed acceleration ($F_{net} = ma$). 3. The drag force is the difference between the applied force and the net force.

Example: Rugby Players (Problem 16)

A rugby player (90.0 kg) is accelerating at 1.20 $\mathrm{m/s^2}$ backward while being pushed by an opposing player exerting 800 N.

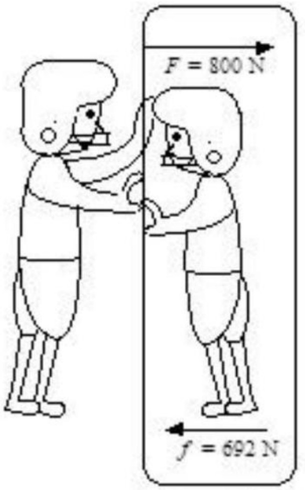
(a) What is the force of friction between the losing player's feet and the grass?

(b) What force must the winning player (110 kg) exert on the ground to move forward at the same acceleration?

Problem 16 - Solution (a)

System of Interest: Losing Player

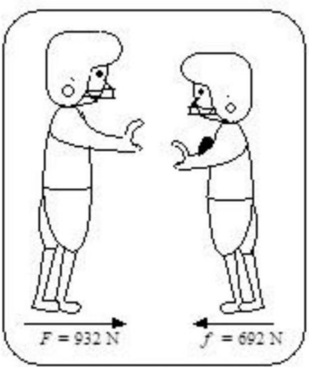
- $F_{\text{net}} = F_{push} - f = ma$
- $f = F_{push} - ma$
- $f =$ $800\text{ N} - (90.0\text{ kg})(1.20\text{ m/s}^2)$
- $f = 800\text{ N} - 108\text{ N}$
- $\boxed{f = 692\text{ N}}$



Problem 16 - Solution (b)

System of Interest: Both Players

- Let F_{ground} be the force the winner exerts on the ground.
- $F_{net} = F_{ground} - f = (m_1 + m_2)a$
- $F_{ground} = (m_1 + m_2)a + f$
- $F_{ground} =$ $(90.0{+}110)\text{kg}(1.20\text{m/s}^2){+}692\text{N}$
- $F_{ground} = 240\text{N} + 692\text{N}$
- $\boxed{F_{ground} = 932\text{N}}$



Reading Homework

Please read the following sections from Chapter 4 in your textbook. They contain important examples of specific forces we will use in later chapters.

- **Section 4.5: Normal, Tension, and Other Examples of Forces**
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  - Detailed examples of Normal Force on inclines and Tension.
- **Section 4.8: Extended Topic: The Four Basic Forces**
  - An introduction to the fundamental forces of nature (Gravitational, Electromagnetic, Weak Nuclear, Strong Nuclear).

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- The key to solving complex dynamics problems is to correctly define the system of interest.
  - This choice determines which forces are **external** (and included in $\vec{F}_{net}$) and which are **internal** (and ignored).
- Every analysis should begin with a **Free-Body Diagram** for your chosen system.