PHYS12 CH: 4.1-4.4, 4.6-4.8

Force, Mass, Systems, and Fundamental Forces

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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.

Concept: What is a Force?

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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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- 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"]

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

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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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  - *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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  - $m_{sys2} = 19.0$ kg
  - $a = 1.5$ m/s^2
  - $f = 24.0$ 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.

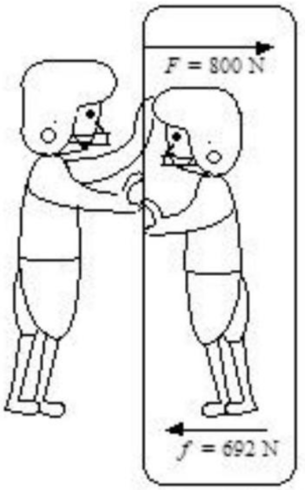
(a) What is the force of friction between the losing player's feet and the grass?

(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

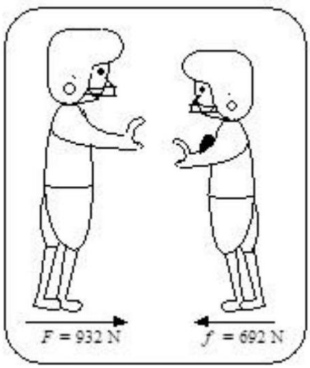
- $F_{net} = F_{push} - f = ma$
- $f = F_{push} - ma$
- $f =$ $800\text{ N} - (90.0\text{ kg})(1.20\text{ m/s}^2)$
- $f = 800\text{ N} - 108\text{ N}$
- $\boxed{f = 692\text{ N}}$



Problem 16 - Solution (b)

System of Interest: Both Players

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



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  - Two-dimensional force problems with vector addition
  - Objects with multiple forces at different angles
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Section 4.7: Further Applications of Newton's Laws

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  - Two-dimensional force problems with vector addition
  - Objects with multiple forces at different angles
  - Real-world applications with drag and resistance
- These problems integrate kinematics with dynamics
- Strategic use of coordinate systems and trigonometry is essential

Example: Drag Force on a Barge (Example 4.7)

Problem Summary

Two tugboats push a barge at perpendicular angles ($F_1 = 2.7 \times 10^5$ N in x-direction, $F_2 = 3.6 \times 10^5$ N in y-direction). The barge (mass 5.0×10^6 kg) accelerates at 7.5×10^{-2} m/s^2. Find the drag force.

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Solution Approach

- Find total applied force: $F_{app} = \sqrt{F_1^2 + F_2^2} = 4.5 \times 10^5$ N
- Apply Newton's 2nd Law: $F_{net} = F_{app} - F_D = ma$
- Result: $F_D = 7.5 \times 10^4$ N (opposite to motion direction)

Visualization: Barge Problem (Figure 4.21)

[Diagram based on Figure 4.21]

Two-Dimensional Force Analysis:

- Two tugboats apply perpendicular forces to a barge
- Force vectors add using Pythagorean theorem
- Resultant $\vec{F}_{app}$ points at angle: $\theta = \tan^{-1}(F_2/F_1) = 53$
- Drag force $\vec{F}_D$ opposes motion (fluid resistance)
- Net force determines acceleration via $\vec{F}_{net} = m\vec{a}$

[Image: Top view of barge with two tugboat force vectors and drag]

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Section 4.8: The Four Basic Forces

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Section 4.8: The Four Basic Forces

Understanding the Fundamental Forces of Nature

- One of the most remarkable simplifications in physics:
- Only four distinct forces account for ALL known phenomena
- Nearly all forces we experience directly are due to ONE basic force: the electromagnetic force
- The gravitational force is the only other force we experience directly

The Four Basic Forces

1. **Gravitational Force**

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Key Concept

All forces act through the exchange of microscopic carrier particles. The characteristics of basic forces are determined by the types of particles exchanged.

Properties of the Four Basic Forces

Force	Strength	Range	Type	Carrier
Gravitational	10^{-38}	∞	Attractive only	Graviton
Electromagnetic	10^{-2}	∞	Both	Photon
Weak Nuclear	10^{-6}	$< 10^{-18}$ m	Both	W^+, W^-, Z^0
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- Strengths are **relative** to the strong nuclear force
- Nuclear forces act over extremely short ranges (size of nucleus or less)

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- **Long-range**: acts over infinite distances
- Dominant force on astronomical scales (planets, stars, galaxies)
- Affects the nature of space and time (general relativity)
- **Carrier particle**: Graviton (proposed but not yet observed)

Electromagnetic Force

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- **Carrier particle**: Photon

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- **Chemistry**: All chemical reactions are electromagnetic interactions between electrons

Nuclear Forces

Weak Nuclear Force

- Relative strength: 10^{-6}
- Range: $< 10^{-18}$ m
- Responsible for radioactive decay
- Determines nuclear stability
- Carrier: W^+, W^-, Z^0 bosons

Strong Nuclear Force

- **Strongest** force (reference: 1)
- Range: $\approx 10^{-15}$ m
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Important

We don't experience nuclear forces directly, but they determine the structure of all matter.

Concept: Action at a Distance

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Force Field

A force field surrounds an object that creates a force. A second object placed in this field experiences a force that depends on its location. The field itself "carries" the force from one object to another.

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- A force field is a characteristic of the object creating it
- The field does NOT depend on test objects placed in it
- Example: Earth's gravitational field is a function of Earth's mass and distance from its center
- We can write equations for force fields and calculate motions

Visualization: Electric Force Field (Figure 4.24)

[Diagram based on Figure 4.24]

Electric field between opposite charges:

- Field lines show the direction of force on a positive test charge
- Between a positive and negative charge, field lines point from positive to negative
- Closer field lines indicate stronger force
- When a test charge is placed in the field, it experiences a force along the field line direction
- This visualizes how electromagnetic force acts at a distance

[Image showing electric field lines between positive and negative charges]

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  - Both feel a force without touching each other!
- This is how subatomic carrier particles transmit forces

Visualization: Particle Exchange (Figure 4.25)

[Diagram based on Figure 4.25]

Exchange of masses resulting in repulsive forces:

- Person 1 throws basketball toward Person 2
- Force $\vec{F}_{p1}$ on ball creates reaction force $\vec{F}_{B}$ pushing Person 1 backward
- Person 2 catches ball and exerts force $\vec{F}_{p2}$ to stop it
- Force $\vec{F}_{p2}$ creates reaction pushing Person 2 backward
- Both people experience repulsive force without direct contact
- Microscopic version: Particles exchange carrier particles (photons, gluons, etc.)

[Image: Two people exchanging basketball with force vectors shown]

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Profound Simplicity

The universe exhibits remarkable simplicity beneath its apparent complexity. Four forces explain everything we observe.

Modern Research: Large Hadron Collider (Figure 4.26)

[Diagram based on Figure 4.26]

World's largest particle accelerator (Switzerland-France border):

- 27-kilometer circular tunnel underground
- Two high-energy proton beams travel in opposite directions
- Collisions occur at nearly the speed of light
- Energy: 14 trillion electron volts available
- **Goal**: Detect new particles and force carriers
- Notable discovery: Higgs boson (explains why particles have mass)
- External magnets control beam path

[Image: Cross-section of LHC collision tube with beam paths]

Detecting Gravitational Waves: LISA Project (Figure 4.27)

[Diagram based on Figure 4.27]

Space-based gravitational wave detector:

- Three satellites in space above Earth
- Arranged in equilateral triangle (5,000,000 km sides!)
- Measures relative positions to detect passing gravitational waves
- Required accuracy: within 10% of atomic size
- Predicted launch: 2030s
- Will confirm predictions of general relativity
- Graviton (carrier particle) not yet directly observed

[Image: LISA satellite triangle configuration orbiting Earth]

Black Hole Imaging: Event Horizon Telescope (Figure 4.28)

[Diagram based on Figure 4.28]

Supermassive black hole at center of M87 galaxy:

- Image shows polarization from powerful magnetic fields
- Demonstrates electromagnetic force at extreme scales
- Created by combining data from telescopes worldwide
- Black hole's gravity (weakest force!) dominates at massive scales
- Event horizon: boundary where gravity prevents light escape
- Magnetic fields (electromagnetic force) create jets of material

[Image: Polarized light around M87 black hole showing magnetic field structure]

Reading Homework

Please read the following section from Chapter 4 in your textbook:

- **Section 4.5: Normal, Tension, and Other Examples of Forces**
  - Detailed examples of Normal Force on inclines and Tension in various scenarios
  - These are specific applications of the electromagnetic force

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- The key to solving complex dynamics problems is to correctly define the system of interest.
- **All forces in nature** can be explained by just four fundamental forces.
- Every analysis should begin with a **Free-Body Diagram** for your chosen system.