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AP Physics
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The Laws of Motion

Background/Summary

In this unit, we explore Newton's Three Laws of Motion, which describe how forces influence the motion of objects. You'll also work with concepts like friction, tension, and normal force, and learn how to analyze situations using free-body diagrams. Mastery of this material is essential for solving various physics problems involving forces and motion.

Major Topics:

- Newton’s First Law (Inertia)
- Newton’s Second Law (F = ma)
- Newton’s Third Law (Action-Reaction)
- Free-body diagrams
- Friction (static and kinetic)
- Tension and normal force
- Weight vs. mass

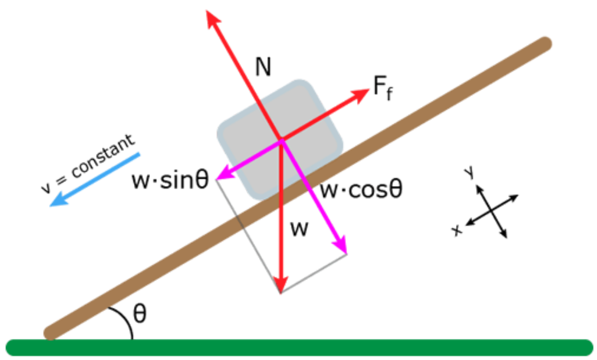
Key Vocabulary:

- **Inertia**: Resistance to change in motion
- **Net force**: Vector sum of all forces
- **Tension Force:** transmitted through a rope, string, etc
- **Normal Force**: Support force from a surface
- **Friction**: Force opposing motion between surfaces
    - $f_k = \mu_K N$
    - $f_s \leq \mu_s N$
- **Weight**: W = mg, a force acting downward due to gravity

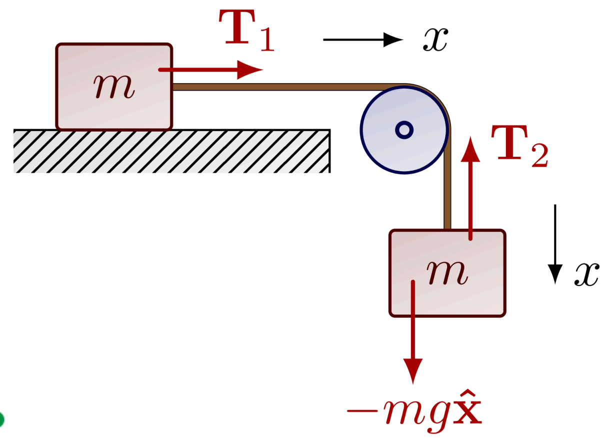
Important Formulas/Values:

- **Newton’s 2nd Law**: $F_{net} = ma$
- **Friction**: $f_k = \mu_K N$, $f_s \leq \mu_s N$
- **Inclined Plane**: $F_{parallel} = mg\sin(\theta)$, $F_{perpendicular} = mg\cos(\theta)$
- **Tension in systems with pulleys**: Depends on setup—use FBDs
- **Acceleration due to gravity:** 9.8 m/s^2

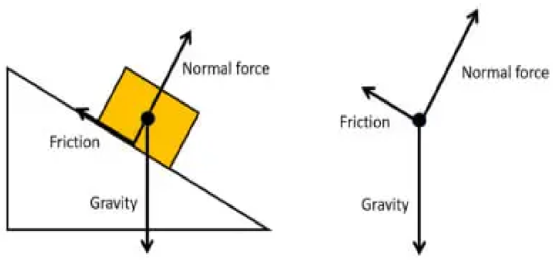
Diagrams:



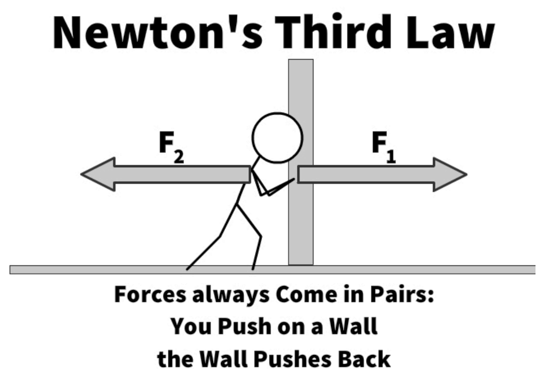
Example of a free-body diagram



Example of tension in pulley systems



Friction vs Normal Force



Visualizing Newton’s Third Law

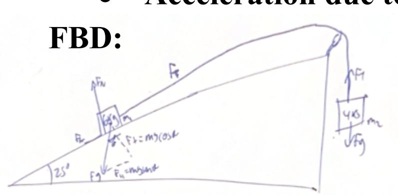
Example Problems:

Problem 1: A 6.0 kg block is on a 25° incline. It is connected via a massless rope over a frictionless pulley to a hanging 4.0 kg block. The coefficient of kinetic friction between the block and the incline is μ□ = 0.15. Find the acceleration of the system and the tension in the rope.

Given:

- **Mass on incline**: m_A = 6.0 kg
- **Mass hanging**: m_B = 4.0 kg
- **Incline angle**: θ = 25°
- **Coefficient of kinetic friction**: $\mu_k = 0.15$
- **Acceleration due to gravity**: $g = 9.8\ m/s^2$

FBD:



Solution:

Let block A (6.0 kg) be on the incline and block B (4.0 kg) be hanging.
Let acceleration be *a*, positive if the system accelerates **downward for block B**.

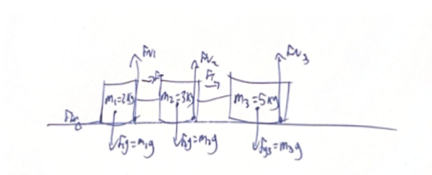
- **Forces on A (incline)**:
    - $F_T - F_{parallel} - f_k = m_A a$
    - $f_k = \mu_k F_N = \mu_k m_A g \cos(\theta)$
    - $F_{parralel} = m_A g \sin(\theta)$
- **Forces on B (hanging)**:
  $m_B g - F_T = m_B a$

Substitute:

1. $f_K = \mu_k m_A g \cos(\theta) = (0.15)\,(6.0)\,(9.8) \cos(25^o) \approx 7.99$ N
2. $F_{parralel} = m_A g \sin(\theta) = (6.0)\,(9.8) \sin(25^o) \approx 24.85$N

Equation for A:
$F_T = m_A a + F_{parallel} + f_k = 6.0a + 24.85 + 7.99 = 6.0a + 32.84$
Equation for B:
$m_B g - F_T = m_B a = (4.0)\,(9.8) - F_T = 4.0a \Rightarrow 39.2 - F_T = 4.0a$
Substitute and solve:
$39.2 - F_T = 4.0a$
$F_T = 6.0a + 32.84$
$39.2 - (6.0a + 32.84) = 4.0a$
$6.33 = 10.0a \Rightarrow a = \frac{6.33}{10} = 0.633 \text{ m/s}^2$
Tension:
$F_T = 6.0a + 32.84 = (6.0)\,(0.633) + 32.84 =$ **36.738 N**

Problem 2: Three blocks (2 kg, 3 kg, and 5 kg, respectively) are connected by strings and lie on a horizontal surface. A force of 50 N pulls on the 2 kg block. The coefficient of kinetic friction between all blocks and the surface is μ□ = 0.2. Find the acceleration of the system and the tension between the 3 kg and 5 kg blocks.
FBD:



Given:

- **Masses**: $m_1 = 2$ kg, $m_2 = 3$ kg, $m_3 = 5$ kg
- **Pulling force**: F=50 N
- **Coefficient of kinetic friction**: $\mu_k = 0.2$
- **Surface is horizontal**

- **g** = 9.8 m/s^2

Solution:

Total mass: m_{total} = 2 + 3 + 5 = 10 kg \text{kg}mtotal=2+3+5=10kg

Total friction:

$f_{total} = \mu_k m_{total} g$ = (0.2) (10) (9.8) = 19.6 N

Net force:

F_{net} = 50 − 19.6 = 30.4 N

Acceleration:

$a = \frac{F_{net}}{m_{total}} = \frac{30.4}{10}$ = 3.04 m/s^2

Tension between 3 kg and 5 kg blocks:

This tension pulls only the **5 kg** block forward against its friction.

Friction on 5 kg: f = (0.2) (5) (9.8) = 9.8 N

So:

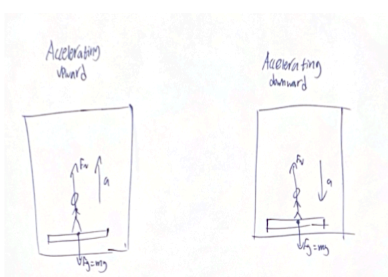
F_T = ma + f = (5) (3.04) + 9.8 = **25.0 N**

Problem 3: A person of mass 70 kg stands on a scale inside an elevator. The elevator accelerates upward at 2.5 m/s² for 4.0 seconds, stops, and then accelerates downward at 3.5 m/s² for another 3.0 seconds. Determine: a) The scale reading during the upward acceleration b) The scale reading during downward acceleration c) The person's apparent weight at each stage

Given:

- **Person's mass**: m=70 kg
- **g** = 9.8 m/s^2
- **Upward acceleration**: a_{up}=2.5 m/s^2
- **Downward acceleration**: a_{down} = 3.5 m/s^2

FBD:



Solution:

Apparent weight is the normal force N from the scale.

a) **Upward acceleration**:

F_N = m(g+a) = 70(9.8+2.5) = **861 N**

b) **Downward acceleration**:

F_N = m(g−a) = 70(9.8−3.5) = **441 N**