# Homework Set: Lectures 3 & 4
# Kinematics and Newton's Second Law

**Instructions:**

- Show all work clearly. Box or highlight final answers.
- Use appropriate units and directions (e.g., "to the right", "up the incline").
- Unless otherwise stated, take $g = 9.8\,\mathrm{m/s^2}$ and neglect air resistance.

## Problem 1: Multi-Step Static Equilibrium — Hanging Sign with Wind

A uniform rectangular sign of mass $m = 25\,\mathrm{kg}$ hangs at rest from two cables attached to a wall, as shown. The left cable makes an angle of $35^\circ$ above the horizontal, and the right cable makes an angle of $55^\circ$ above the horizontal. A steady horizontal wind exerts a force of magnitude $60\,\mathrm{N}$ on the sign *toward the right.*

(a) Draw a clear free-body diagram (FBD) of the sign, labeling:
  - The weight $W$,
  - The tensions $T_1$ and $T_2$ in the left and right cables,
  - The wind force $F_{\text{wind}}$.

(b) Write the equilibrium equations for the $x$- and $y$-components of the forces.

(c) Solve for the tensions $T_1$ and $T_2$ in the two cables.

(d) Which cable is under greater tension? Give a brief explanation based on geometry and your results.

## Problem 2: Block on Rough Horizontal Surface with Angled Pull

A box of mass $m = 18\,\mathrm{kg}$ rests on a horizontal surface. The coefficient of kinetic friction between the box and the floor is $\mu_k = 0.25$. A person pulls on the box with a rope that makes an angle of $30^\circ$ above the horizontal, exerting a constant force of magnitude $F$.

(a) Draw a free-body diagram of the box, labeling all forces (including the normal force and friction).

(b) Express the normal force $N$ in terms of $m$, $g$, and $F$.

(c) Write the $x$- and $y$-component equations from Newton's Second Law *during motion*, in terms of $F$, $N$, and the acceleration $a$.

(d) Suppose the box moves at constant speed once it gets going. Find the *specific* value of $F$ that makes the acceleration zero.

(e) The person now increases the pulling force to $F = 120\,\mathrm{N}$ at the same angle. Find the resulting acceleration of the box.

(Hint: Friction is kinetic once the box is moving: $f_k = \mu_k N$.)

## Problem 3: Velocity–Time Graph, Displacement, and Forces

A cart of mass $2.0\,\mathrm{kg}$ moves along a straight track under the influence of varying horizontal forces. Its velocity as a function of time is shown qualitatively below:

- From $t = 0$ to $t = 2.0\,\mathrm{s}$, the velocity increases linearly from 0 to $4.0\,\mathrm{m/s}$.
- From $t = 2.0\,\mathrm{s}$ to $t = 5.0\,\mathrm{s}$, the velocity remains constant at $4.0\,\mathrm{m/s}$.
- From $t = 5.0\,\mathrm{s}$ to $t = 7.0\,\mathrm{s}$, the velocity decreases linearly from $4.0\,\mathrm{m/s}$ to 0.

Assume motion is along the $+x$ direction.

(a) Sketch the velocity–time graph on a set of axes and label all key points.

(b) Using the graph, determine the total displacement of the cart between $t = 0$ and $t = 7.0\,\mathrm{s}$.

(c) Determine the average velocity over the entire interval $0 \le t \le 7.0\,\mathrm{s}$.

(d) Find the acceleration (constant) in each of the three time intervals: $0-2$ s, $2-5$ s, and $5-7$ s.

(e) If the cart experiences negligible friction, sketch a *qualitative* horizontal force–time graph $F_x(t)$ over the same time interval. Explain how its shape relates to the acceleration found in part (d).

(Hint: Remember that area under the $v$–$t$ graph gives displacement, and $F = ma$.)

## Problem 4: Projectile Off a Cliff with Required Launch Speed

A projectile is launched from the edge of a cliff of height 45 m above level ground. It is launched with an initial velocity making an angle of 40° above the horizontal. The projectile must land at a point on the ground that is horizontally 60 m from the base of the cliff.

Assume no air resistance.

(a) Draw a diagram of the situation, labeling the initial velocity components $v_{0x}$ and $v_{0y}$, the cliff height, and the horizontal range.

(b) Write the horizontal and vertical position equations as functions of time $t$, using $x = 0$ and $y = 0$ at the base of the cliff directly below the launch point.

(c) Write an equation that expresses the condition that the projectile lands at $(x, y) = (60\,\mathrm{m}, 0)$.

(d) Use your equations to *solve algebraically* for the required launch speed $v_0$ (in terms of $g$ and known numbers). Show algebra carefully. (You may leave the final answer in symbolic form or evaluate numerically.)

(e) For your found $v_0$, determine the *time of flight* to reach the ground.

## Problem 5: Two-Mass System with Friction on an Incline

A block of mass $m_1 = 6.0\,\mathrm{kg}$ sits on a rough incline that makes an angle of 30° above the horizontal. The coefficient of kinetic friction between $m_1$ and the incline is $\mu_k = 0.20$. The block is connected by a light string over a frictionless pulley to a hanging block of mass $m_2$. The string is parallel to the incline on the $m_1$ side.

You observe experimentally that when the system is released from rest, $m_2$ moves *downward* and $m_1$ moves *up the incline* with a constant acceleration of magnitude $1.2\,\mathrm{m/s^2}$.

(a) Draw separate free-body diagrams for $m_1$ and $m_2$, labeling all forces (including weight components, normal force, friction, and tension).

(b) For $m_1$, write Newton's Second Law along the incline (parallel direction), taking *up the incline* as positive.

(c) For $m_2$, write Newton's Second Law in the vertical direction, taking downward as positive.

(d) Use the two equations to solve for the unknown tension $T$ and the unknown mass $m_2$. (You may solve algebraically first, then substitute numerical values.)

(e) Suppose now that $m_2$ is kept the same, but the coefficient of kinetic friction is increased to $\mu_k = 0.35$. Predict qualitatively:

- Which direction will the system accelerate (if at all)?
- Will the magnitude of the acceleration be larger, smaller, or zero compared to the original case? Justify using your force equations.