FORCES DAY 1: SYSTEMS & CENTER OF MASS

WARMUP **Unit 1 Bridge**

A cart accelerates from rest at 2.0 m/s² for 4.0 s. Find its final velocity and displacement — units in every step. (Unit 1 never leaves; this unit explains *where the acceleration comes from*.)

Physics in the Wild — Wobbling Stars: Astronomers discovered hundreds of exoplanets without ever seeing one. A star and its planet both orbit their shared *center of mass*, so the star wobbles — and that wobble shows up in its light. The center of mass is the point a system acts through, and it's how physicists treat a whole messy object as one dot.

SYSTEMS, AND THE TWO KINDS OF FORCES

A system is whatever you draw the boundary around. Forces from outside the boundary are external; forces between parts inside it are internal and cancel in pairs.

Contact forces (touch required):
normal, tension, friction, applied push/pull, spring

Field forces (act at a distance):
gravity (this unit), electric & magnetic (later courses)

CENTER OF MASS

$$x_{cm} = (m_1x_1 + m_2x_2 + \ldots) / (m_1 + m_2 + \ldots)$$

The units prove it: (kg·m)/(kg) = m — a position, as expected. The center of mass sits closer to the heavier object.

FINDING THE BALANCE POINT

WE DO **Exercise 1: Equal Masses**

A 2.0 kg ball sits at $x = 0$ and another 2.0 kg ball sits at $x = 4.0$ m. Find the center of mass. Before computing: where do you *expect* the center of mass for equal masses?

YOU DO **Exercise 2: Unequal Masses**

A 3.0 kg block sits at $x = 0$ and a 1.0 kg block sits at $x = 8.0$ m. Find the center of mass. Check: is the answer closer to the heavier block?

WE DO **Exercise 3: Three Objects**

Masses of 2.0 kg, 2.0 kg, and 4.0 kg sit at $x = 0$, $x = 3.0$ m, and $x = 6.0$ m. Find the center of mass — keep the units visible in the numerator and denominator.

CALCULUS CORNER — THE WEIGHTED AVERAGE, FORMALLY

Everything you just did is one formula: $\mathbf{x_{cm} = (m_1x_1 + m_2x_2 + \ldots)/(m_1 + m_2 + \ldots)}$ — each position weighted by its share of the mass. Check Exercise 3 with it: $(2\cdot0 + 2\cdot3.0 + 4\cdot6.0)$ kg·m / 8.0 kg = 30/8 m = 3.75 m.

For a solid object — a rod, a plate — the "sum over pieces" becomes a sum over infinitely many tiny pieces. That's an integral, and it arrives in Unit 4 once accumulation is second nature.

The center of mass needs no mass at its location. A donut's center of mass is in the hole. For a two-object system it lies on the line between them — but never beyond either object.

NAMING THE FORCES

YOU DO **Exercise 4: Contact or Field?**

For each force, write C (contact) or F (field), and name the object that exerts it.

Force	C or F?	Exerted by…
The weight of your backpack		
Tension in a rope-swing rope		
The floor holding you up		
Friction on sliding luggage		
The Moon's pull on Earth's oceans		

CHALLENGE **Exercise 5: Place the Mass**

A 3.0 kg block sits at $x = 0$. Where must you place a 1.0 kg block so the system's center of mass lands at $x = 1.0$ m? Set up the center-of-mass equation and solve for the unknown position.

PAPER PRACTICE

PRACTICE PROBLEMS

P1 Two Objects

A 4.0 kg mass sits at x = 1.0 m and a 2.0 kg mass at x = 7.0 m. Find the center of mass.

P2 Three Equal Masses

Three 1.0 kg masses sit at x = 0, x = 2.0 m, and x = 7.0 m. Find the center of mass.

P3 Internal or External?

Two skaters push off each other. Treating *both skaters together* as the system, is each push internal or external? Does the system's center of mass move because of the pushes? Answer in one or two sentences.

P4 The Spinning Hammer

A thrown hammer tumbles end over end, yet one point of the hammer traces a smooth projectile arc. Which point traces the smooth arc, and why does that specific point ignore the tumbling?