FULL REVIEW

# Full Review: Center of Mass and Systems of Particles

Review the essential ideas, system models, and reasoning tools for center of mass and systems of particles.

| ◷ TIME | ◎ BEST FOR | ✓ FINISH WITH |
|---|---|---|
| 60 minutes | A complete unit review | A readiness check |

**After this full review, you'll be able to…**
identify a system's center of mass, interpret how mass distribution affects its location, and explain how external forces control center-of-mass motion.

## HOW TO USE THIS GUIDE

Work through the stages in order. Write directly in the spaces provided, check your work in the Solutions section, and finish by choosing the next resource that matches your confidence.

Choose how you want to review: work through this guide, follow the online review, or watch the video review.

**Start the Review Online →**
**Watch the Video Review →**

## YOU WILL NEED

Pencil or pen • Calculator if needed • Approximately 60 minutes

FR-02 • PHYSICS SENSEI UNIT REVIEW

# Physics Sensei Unit Review

Use this Physics Sensei Unit Review to reinforce key concepts, prepare for homework, and review before a quiz or exam.

| | |
|---|---|
| **UNIT: MEC-U19**<br>**TOPIC FAMILY: Mechanics**<br>**TOPIC: Center of Mass and Systems of Particles**<br>**COURSE LEVEL: Foundational introductory college physics** | **BEST USED**<br>✓ **To reinforce key concepts**<br>✓ Before starting homework<br>✓ Before a quiz or exam |

**Continue with Physics Sensei →**

Physics Sensei is an independent educational resource organized around core college-physics ideas, problem-solving models, and study workflows.

FR-03 • YOUR REVIEW PLAN

# Your Review Plan

Complete these six stages in order. Each stage builds on the previous one and prepares you for the final readiness check.

**6 stages • Approximately 60 minutes**



PRINTING TIP

For student copies, print double-sided and keep the Solutions section after the student activities so learners attempt each activity before checking their work.

FR-04 • STAGE 1 OF 6

# Warm-Up Check

Before you begin, take a moment to see what you already remember. Do not worry about getting everything right. This is only a starting point.

ACTIVITY 1

### Recall Activity 1

Use the idea of a mass-weighted average to predict where a system balances.

*Two objects lie on a straight line. One is much more massive than the other. Without calculating, explain whether the center of mass lies closer to the lighter object, halfway between them, or closer to the heavier object.*

ACTIVITY 2

### Recall Activity 2

Separate motion of individual particles from motion of the system as a whole.

*Two skaters push apart from rest on nearly frictionless ice. Their individual velocities change in opposite directions. What can you say about the motion of the center of mass if the net external horizontal force is negligible?*

FR-04 • WARM-UP CHECK CONTINUED

ACTIVITY 3

## Recall Activity 3

Distinguish internal forces from the external forces that control center-of-mass acceleration.

*Two carts collide on a nearly frictionless track. The forces the carts exert on each other are large during the collision. Are those forces internal or external to the two-cart system, and can they by themselves accelerate the center of mass of that system?*

### Ready to strengthen your understanding?

You’ve refreshed what you already know. Next, reinforce the essential concepts that will help you solve problems with confidence.

**Continue to Core Concepts — page 6 →**

FR-05 • STAGE 2 OF 6

# Core Concepts

Let's rebuild the key ideas one step at a time. Focus on understanding the relationships before worrying about solving problems.

KEY CONCEPT 1

## Center of Mass as the System's Balance Point

The center of mass is the mass-weighted average position of a system. For two unequal masses, the center of mass lies closer to the more massive object. For symmetric mass distributions, symmetry can often locate the center of mass without calculation. The center of mass is a property of the chosen system, so always define the system before reasoning about it.

**Conceptually: center of mass = mass-weighted average position of the chosen system.**

EXAMPLE Imagine two students holding a light board, with a heavy backpack placed near one end. The system's center of mass shifts toward the backpack because more of the system's mass is concentrated there.

SENSEI NOTE The center of mass does not have to coincide with a particle or even lie inside the material of an object. It represents the mass-weighted position of the entire chosen system.

KEY CONCEPT 2

## Motion of the Center of Mass

A system can contain particles moving in very different ways while its center of mass follows a much simpler motion. The center-of-mass velocity represents the overall translational motion of the system, and changes in that motion are caused by net external force. Internal pushes, pulls, collisions, or explosions can rearrange the particles without changing the center-of-mass motion when external force is negligible.

**System model: net external force determines the acceleration of the center of mass.**

EXAMPLE If two skaters push apart while external horizontal forces are negligible, each skater moves, but the center of mass remains at rest if it was initially at rest.

SENSEI NOTE Internal forces can strongly change the motion of individual particles. They do not, by themselves, determine the acceleration of the center of mass of the complete system.

FR-05 • CORE CONCEPTS CONTINUED

KEY CONCEPT 3

## Systems of Particles: Internal vs External Interactions

Before analyzing a multi-particle problem, define the system boundary. Forces between particles inside that boundary are internal. Forces exerted by objects outside the boundary are external. Internal forces can transfer momentum among particles, but the net external force governs the motion of the system's center of mass.

**Decision rule: define the system first; then identify which forces cross the system boundary.**

EXAMPLE During a collision between two carts, the contact forces are internal if both carts belong to the system. Friction from the track or a push from a person would be external interactions.

SENSEI NOTE A force is not inherently internal or external. Its classification depends on the system you choose.

### Ready to apply these ideas?

You've reinforced the essential concepts. Now put them into practice by working through guided examples and building your problem-solving confidence.

**Continue to Guided Practice — page 8 →**

FR-06 • STAGE 3 OF 6

# Guided Practice

Now it's time to apply what you've reviewed. Work through each activity in order. The examples become gradually more challenging, and each prepares you for the final readiness check.

PRACTICE 1

## Worked Example

Use the mass distribution to reason about the center of mass before calculating anything.

*Two identical carts are placed at opposite ends of a light track. Where is the center of mass of the two-cart system? How would your answer change if one cart were replaced by a much heavier cart?*

FR-06 • GUIDED PRACTICE CONTINUED

PRACTICE 2

## Guided Problem

Track the center of mass separately from the motion of the individual objects.

*Two people stand at rest on low-friction carts and push apart. Describe what happens to each person and to the center of mass of the two-person system if horizontal external forces are negligible.*

PRACTICE 3

## Independent Problem

Define the system boundary before deciding which interactions are internal.

*Two carts collide while a person outside the two-cart system briefly pushes one cart. Classify the cart-on-cart forces and the person-on-cart force as internal or external to the two-cart system. Which interaction can change the motion of the center of mass?*

### Ready to check your understanding?

You've practiced the essential skills with guidance. Now solve a few short problems on your own and confirm you're ready to move forward.

**Continue to Confidence Check — page 10 →**

FR-07 • STAGE 4 OF 6

# Confidence Check

You've rebuilt the key ideas and practiced them with guidance. Now try these short questions on your own to check your understanding before moving on.

QUICK CHECK 1

### Locate the Center of Mass Conceptually

Use mass distribution, not geometric midpoint alone.

*A light object and a heavy object are separated by several meters. Is the center of mass closer to the light object, the midpoint, or the heavy object? Explain.*

QUICK CHECK 2

### Check Center-of-Mass Motion

Reason from the net external force on the complete system.

*A system is initially at rest. Its parts push apart internally while the net external force is zero. Can the center of mass begin accelerating? Explain.*

FR-07 • CONFIDENCE CHECK CONTINUED

QUICK CHECK 3

## Classify Internal and External Forces

State the system boundary first.

*For a system containing two colliding carts, classify the contact forces the carts exert on each other. Then classify a friction force exerted by the floor on one cart. Which type determines the center-of-mass acceleration?*

HOW DID IT GO?

**I answered ____ of 3 questions correctly.**

Use the Solutions section to check your reasoning, then take one final look at the essential ideas.

**You've checked your understanding.**

Take one final look at the essential ideas before deciding what to do next.

**Continue to Summary — page 12 →**

FR-08 • STAGE 5 OF 6

# Summary

Before moving on, take one final look at the most important ideas from this review.

KEY TAKEAWAY 1

### Locate the Center of Mass by Mass Distribution

The center of mass is a mass-weighted position, so it shifts toward regions where more of the system's mass is concentrated.

KEY TAKEAWAY 2

### Separate Particle Motion from System Motion

Particles can move in complicated ways while the center of mass follows the motion set by the system's overall momentum and external forces.

KEY TAKEAWAY 3

### Define the System Before Classifying Forces

Internal and external are system-dependent labels. Only the net external force controls the acceleration of the center of mass.

MY ONE-SENTENCE SUMMARY

In my own words, the most important idea is:

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**Ready for your next step?**

You've reviewed the essential ideas one last time. Now choose the resource that best matches how confident you feel.

**Continue to Next Step — page 16 →**

ANSWER KEY • CHECK AFTER ATTEMPTING

# Solutions and Explanations

Use these solutions to check your reasoning—not only your final answer. Use each answer and explanation to identify the step that supports the result.

WARM-UP • ACTIVITY 1

### Recall Activity 1

Closer to the heavier object.

WHY IT WORKS Center of mass is a mass-weighted average position. The larger mass contributes more strongly, pulling the center of mass toward its location.

WARM-UP • ACTIVITY 2

### Recall Activity 2

If the center of mass was initially at rest, it remains at rest while the skaters move apart.

WHY IT WORKS The push between the skaters is internal to the two-skater system. With negligible net external horizontal force, the center-of-mass velocity does not change.

WARM-UP • ACTIVITY 3

### Recall Activity 3

The cart-on-cart forces are internal to the two-cart system. They cannot by themselves accelerate that system's center of mass.

WHY IT WORKS Internal forces act between members of the chosen system. Center-of-mass acceleration is determined by the net force exerted on the system from outside its boundary.

SOLUTIONS • GUIDED PRACTICE

PRACTICE 1

### Worked Example

For identical carts, the center of mass is at the midpoint. Replacing one cart with a much heavier cart shifts the center of mass toward the heavier cart.

WHY IT WORKS  Equal masses contribute equally to the mass-weighted position. When one mass increases, its position contributes more strongly to the system average.

PRACTICE 2

### Guided Problem

The two people move in opposite directions, but the center of mass remains at rest if it was initially at rest and the net external horizontal force is negligible.

WHY IT WORKS  The push between the two people is internal to the chosen two-person system. With negligible net external horizontal force, the center-of-mass velocity cannot change.

PRACTICE 3

### Independent Problem

The cart-on-cart forces are internal to the two-cart system. The person-on-cart force is external. The external interaction can change the motion of the center of mass.

WHY IT WORKS  Internal forces act between members of the system and cancel in the system-level force balance. A force exerted by an object outside the system contributes to the net external force and can accelerate the center of mass.

SOLUTIONS • CONFIDENCE CHECK

QUICK CHECK 1

### Locate the Center of Mass Conceptually

The center of mass is closer to the heavy object than to the midpoint.

WHY IT WORKS The center of mass is a mass-weighted average position, so the heavier object contributes more strongly to the result.

QUICK CHECK 2

### Check Center-of-Mass Motion

No. The center of mass cannot begin accelerating when the net external force is zero.

WHY IT WORKS Internal forces can redistribute motion among the particles, but the acceleration of the complete system's center of mass is set by the net external force.

QUICK CHECK 3

### Classify Internal and External Forces

The cart-on-cart contact forces are internal. Friction from the floor is external. The net external force determines the center-of-mass acceleration.

WHY IT WORKS Internal and external are defined by the chosen system boundary. Only forces crossing that boundary contribute to the net external force on the system.

READINESS GUIDE

3 correct: You're ready to continue. • 2 correct: Review the missed idea, then continue. • 0–1 correct: Revisit Core Concepts or choose more practice.

FR-09 • STAGE 6 OF 6

# Next Step: Continue Learning

Great work! You've completed this review. Choose the next resource that best matches how confident you feel.

| ? I'm Still Unsure | ◎ I Need More Practice | ✓ I'm Ready |
| --- | --- | --- |
| Review the key ideas and examples again. | Continue with additional practice for this topic. | Continue to the next recommended resource. |
| **Review again: return to Warm-Up Check on page 4.** | **Go to Practice →** | **Continue →** |

RECOMMENDED LINKS

**Review again: return to Warm-Up Check on page 4.**

**Find additional practice →**

**Choose another type of physics help →**

Continue reviewing with these companion resources.

**Start the Review Online →**
**Watch the Video Review →**

**PHYSICS HELP THAT MAKES SENSE**

A Physics Sensei review never ends at the last question. It always guides you toward the next useful step.

**PhysicsSensei.com**