FULL REVIEW

Full Review: Center of Mass and Systems of Particles

Review the essential center-of-mass relationships, system momentum, and external-force models used in algebra-based mechanics.

TIME	BEST FOR	FINISH WITH
60 minutes	A complete unit review	A readiness check

After this full review, you'll be able to…

calculate center of mass in one and two dimensions, connect total momentum to center-of-mass velocity, and analyze how net external force changes 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
TOPIC FAMILY: Mechanics
TOPIC: Center of Mass and Systems of Particles
COURSE LEVEL: Algebra-based introductory college physics

BEST USED

- ✓ **To reinforce key concepts**
- ✓ Before starting homework
- ✓ 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

1 **Warm-Up Check — page 4** Activate prior knowledge.	2 **Core Concepts — page 6** Review the essential ideas.	3 **Guided Practice — page 8** Apply what you learned.
4 **Confidence Check — page 10** Confirm your understanding.	5 **Summary — page 12** Review the key ideas.	6 **Next Step — page 16** Continue your learning.

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 a mass-weighted average to locate the center of mass.

A 2.0 kg mass is at x = 1.0 m and a 3.0 kg mass is at x = 5.0 m. Find xCM.

ACTIVITY 2

Recall Activity 2

Relate total momentum to the velocity of the center of mass.

A 2.0 kg cart moves at +4.0 m/s and a 3.0 kg cart moves at -1.0 m/s. Find the total momentum and the center-of-mass velocity.

ACTIVITY 3

Recall Activity 3

Use net external force to determine center-of-mass acceleration.

A 6.0 kg system experiences a net external force of 18 N in the +x direction. Find the acceleration of its center of mass.

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

Calculating Center of Mass for Discrete Particles

For discrete particles, the center of mass is found by weighting each position by its mass and dividing by the total mass. In two dimensions, apply the same weighted-average rule separately to x and y coordinates. Define the system first and keep units consistent.

$$x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i} \qquad y_{CM} = \frac{\sum_i m_i y_i}{\sum_i m_i}$$

EXAMPLE For 2.0 kg at x = 1.0 m and 3.0 kg at x = 5.0 m, xCM = [2(1) + 3(5)]/5 = 3.4 m.

SENSEI NOTE Do not average positions unless the masses are equal. The center of mass is a weighted average, not generally the geometric midpoint.

KEY CONCEPT 2

Center-of-Mass Velocity and Total Momentum

The total momentum of a system equals the total mass multiplied by the velocity of the center of mass. This relationship lets you replace a complicated collection of particle momenta with one system-level quantity. If net external force is zero, total momentum and center-of-mass velocity remain constant.

$$\mathbf{V}_{CM} = \frac{d\mathbf{r}_{CM}}{dt} \qquad \mathbf{P} = \sum_i m_i \mathbf{v}_i = M\mathbf{V}_{CM}$$

EXAMPLE A 2.0 kg cart at +4.0 m/s and a 3.0 kg cart at -1.0 m/s have P = 8 - 3 = 5 kg·m/s. With M = 5.0 kg, VCM = P/M = +1.0 m/s.

SENSEI NOTE Momentum can be redistributed among particles by internal interactions while the system's total momentum remains unchanged when the net external force is zero.

KEY CONCEPT 3

External Force and Center-of-Mass Acceleration

For a system of particles, the net external force equals the total mass multiplied by the acceleration of the center of mass. Internal forces cancel in the system force sum under the usual Newtonian pairwise-force model, so they can change individual motions without determining the center-of-mass acceleration.

$$\frac{d\mathbf{P}}{dt} = \sum \mathbf{F}_{\text{ext}} = M\mathbf{A}_{\text{CM}}$$

EXAMPLE For a 6.0 kg system under a net external force of 18 N, ACM = 18/6.0 = 3.0 m/s^2 in the direction of the net external force.

SENSEI NOTE Always identify the system boundary before labeling a force internal or external. The same interaction can change category when the chosen system changes.

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

Compute the center of mass coordinate by coordinate.

Three particles have masses 2.0 kg at (0,0), 3.0 kg at (4.0,0), and 5.0 kg at (0,6.0) m. Find xCM and yCM.

PRACTICE 2

Guided Problem

Find total momentum first, then divide by total mass.

A 4.0 kg cart moves at +3.0 m/s and a 6.0 kg cart moves at -1.0 m/s. Find the total momentum and VCM.

PRACTICE 3

Independent Problem

Use the net external force on the complete system.

A system of total mass 8.0 kg experiences a constant net external force of 20 N. Find ACM and explain what internal collisions inside the system can and cannot change.

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

Calculate a Two-Dimensional Center of Mass

Apply the mass-weighted average separately to x and y.

Three masses are 1.0 kg at (0,0), 2.0 kg at (3.0,0), and 3.0 kg at (0,4.0) m. Find the center of mass.

QUICK CHECK 2

Connect Momentum to Center-of-Mass Velocity

Use the system's total momentum and total mass.

A 3.0 kg cart moves at +2.0 m/s and a 2.0 kg cart moves at -1.0 m/s. Find the total momentum and the center-of-mass velocity.

FR-07 • CONFIDENCE CHECK CONTINUED

QUICK CHECK 3

Analyze External Force on a System

Use only the net external force to determine center-of-mass acceleration.

A 10 kg system experiences a net external force of 25 N in the +x direction. Find the center-of-mass acceleration. What can internal forces change, and what can they not determine?

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

Use a Mass-Weighted Position

For discrete particles, calculate each coordinate of the center of mass with a mass-weighted average.

KEY TAKEAWAY 2

Connect Total Momentum to Center-of-Mass Velocity

Use P = M VCM to translate between particle-level momentum and system-level motion.

KEY TAKEAWAY 3

Use Only External Force for Center-of-Mass Acceleration

Internal forces redistribute motion inside the system; the net external force determines ACM.

MY ONE-SENTENCE SUMMARY

In my own words, the most important idea is:

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

xCM = 3.4 m.

WHY IT WORKS xCM = [2.0(1.0) + 3.0(5.0)]/(2.0 + 3.0) = 17/5 = 3.4 m.

WARM-UP • ACTIVITY 2

Recall Activity 2

P = +5.0 kg·m/s; VCM = +1.0 m/s.

WHY IT WORKS P = 2.0(+4.0) + 3.0(-1.0) = +5.0 kg·m/s. With total mass 5.0 kg, VCM = P/M = +1.0 m/s.

WARM-UP • ACTIVITY 3

Recall Activity 3

ACM = +3.0 m/s^2.

WHY IT WORKS net external force = M ACM, so ACM = 18 N / 6.0 kg = 3.0 m/s^2 in the +x direction.

SOLUTIONS • GUIDED PRACTICE

PRACTICE 1

Worked Example

xCM = 1.2 m; yCM = 3.0 m.

WHY IT WORKS The total mass is 10.0 kg. xCM = [2(0)+3(4)+5(0)]/10 = 1.2 m and yCM = [2(0)+3(0)+5(6)]/10 = 3.0 m.

PRACTICE 2

Guided Problem

P = +6.0 kg·m/s; VCM = +0.60 m/s.

WHY IT WORKS P = 4.0(+3.0) + 6.0(-1.0) = +6.0 kg·m/s. With M = 10.0 kg, VCM = P/M = +0.60 m/s.

PRACTICE 3

Independent Problem

ACM = 2.5 m/s^2 in the direction of the net external force. Internal collisions can redistribute momentum among particles but cannot change ACM by themselves.

WHY IT WORKS ACM = net external force/M = 20/8.0 = 2.5 m/s^2. Internal forces occur inside the system boundary and cancel from the net system-force sum.

SOLUTIONS • CONFIDENCE CHECK

QUICK CHECK 1

Calculate a Two-Dimensional Center of Mass

xCM = 1.0 m; yCM = 2.0 m.

WHY IT WORKS The total mass is 6.0 kg. xCM = [1(0)+2(3)+3(0)]/6 = 1.0 m and yCM = [1(0)+2(0)+3(4)]/6 = 2.0 m.

QUICK CHECK 2

Connect Momentum to Center-of-Mass Velocity

P = +4.0 kg·m/s; VCM = +0.80 m/s.

WHY IT WORKS P = 3.0(+2.0) + 2.0(-1.0) = +4.0 kg·m/s. The total mass is 5.0 kg, so VCM = 4.0/5.0 = +0.80 m/s.

QUICK CHECK 3

Analyze External Force on a System

ACM = +2.5 m/s^2. Internal forces can change individual particle velocities and redistribute momentum, but they do not determine the acceleration of the center of mass.

WHY IT WORKS net external force = M ACM gives ACM = 25/10 = +2.5 m/s^2. Only the net external force determines the system center-of-mass acceleration.

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.

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