

FULL REVIEW

Full Review: Heat Engines, Refrigerators, and Heat Pumps — Calculus-Based

Review how heat engines produce work and how refrigerators and heat pumps move heat in a cycle.

 TIME 45–60 minutes	 BEST FOR A complete topic review	 FINISH WITH A readiness check
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After this full review, you'll be able to...

recall the essential ideas, apply them to representative problems, and determine what to study next.

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 45–60 minutes

FR-02 • COURSE ALIGNMENT

Course Alignment

This Physics Sensei Unit Review is an independent learning resource. Use it to reinforce key concepts, prepare for homework, or review before a quiz or exam.

RESOURCE: Physics Sensei Unit Review UNIT ID: THM-U10 TOPIC: Heat Engines, Refrigerators, and Heat Pumps COURSE LEVEL: Calculus-Based	BEST USED ✓ After learning the unit ✓ Before starting homework ✓ Before a quiz or exam
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Replace every double-brace placeholder, update all topic-specific links, and test every hyperlink before publishing. This includes the online review, video review, practice bundle, next recommended resource, and additional-help links.

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 45–60 minutes

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

Identify the energy transfers in a heat engine.

Draw hot and cold reservoirs. Label incoming Q_H , outgoing Q_C , and work W_{out} .

ACTIVITY 2**Recall Activity 2**

Classify useful outputs.

Explain which transfer counts as useful for an engine, refrigerator, and heat pump.

FR-04 • WARM-UP CHECK CONTINUED

ACTIVITY 3

Recall Activity 3

Apply conservation to a cycle.

An engine absorbs 800 J and rejects 600 J. Find work and efficiency.

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 →](#)

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

Heat engines and the first law

For a cyclic engine, $\Delta U = 0$, so $W_{\text{net}} = Q_H - Q_C$ with Q_H and Q_C positive magnitudes. The enclosed area on a P - V diagram is $\oint P \, dV$; clockwise traversal gives positive net work by the gas.

$$Q_H = W_{\text{out}} + Q_C; \eta = W_{\text{out}}/Q_H$$

EXAMPLE A device receives 800 J from a hot source and rejects 600 J. Its work output is 200 J and efficiency is $200/800 = 0.25$, or 25%.

SENSEI NOTE For a full cycle, internal energy returns to its initial value; never equate heat input to work alone.

KEY CONCEPT 2

Refrigerators and heat pumps

For a reversed cycle, $W_{\text{in}} = Q_H - Q_C$. Refrigeration performance is $\text{COP}_R = Q_C/W_{\text{in}}$; heating performance is $\text{COP}_{\text{HP}} = Q_H/W_{\text{in}} = \text{COP}_R + 1$. These relations are energy balances, not ideal-cycle assumptions.

$$Q_H = Q_C + W_{\text{in}}; \text{COP}_R = Q_C/W_{\text{in}}; \text{COP}_{\text{HP}} = Q_H/W_{\text{in}}$$

EXAMPLE A refrigerator removes 300 J from a cold compartment using 100 J of work. It delivers 400 J to the room; $\text{COP}_R = 300/100 = 3$ and $\text{COP}_{\text{HP}} = 400/100 = 4$.

SENSEI NOTE The two COP definitions differ because cooling and heating select different useful outputs.

FR-05 • CORE CONCEPTS CONTINUED

KEY CONCEPT 3

Performance and limits

The reversible upper bound between thermal reservoirs is $\eta_{\text{Carnot}} = 1 - T_C/T_H$ and $\text{COP}_{\text{R,Carnot}} = T_C/(T_H - T_C)$, with absolute temperatures. No cyclic device can exceed its corresponding reversible bound.

$$\eta_{\text{Carnot}} = 1 - T_C/T_H \text{ (temperatures in kelvin)}$$

EXAMPLE At 500 K and 300 K, the reversible engine limit is $1 - 300/500 = 0.40$. A claim of 50% efficiency between these reservoirs violates that limit.

SENSEI NOTE Use kelvin in reservoir-temperature ratios; ideal bounds do not describe every real machine.

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 →](#)

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**

Draw flows, subtract rejected heat, then compute efficiency.

An engine absorbs 1,000 J and rejects 700 J. $W_{\text{out}} = 300 \text{ J}$ and $\eta = 300/1,000 = 0.30$.

FR-06 • GUIDED PRACTICE CONTINUED

PRACTICE 2

Guided Problem

Use separate cooling and heating numerators.

A refrigerator removes 450 J with 150 J work. Find delivered heat, cooling COP, and heating COP. Identify the useful transfer for each ratio.

PRACTICE 3

Independent Problem

Compare an efficiency claim with a reversible limit.

An engine operates between 500 K and 300 K. Could it deliver 500 J of work from 1,000 J of hot-source heat? Compare its claimed efficiency with the reversible limit.

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 →](#)

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**Energy balance**

Calculate work before performance.

An engine absorbs 900 J and rejects 630 J. Find W_{out} and η .

QUICK CHECK 2**Reversed cycle**

Use separate cooling and heating numerators.

A device draws 600 J from the cold reservoir using 200 J of work. Find Q_H , COP_R , and COP_{HP} .

FR-07 • CONFIDENCE CHECK CONTINUED

QUICK CHECK 3

Temperature limit

Use absolute temperatures.

For reservoirs at 600 K and 300 K, find the maximum reversible engine efficiency. Is a 60% claim possible?

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 →](#)

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

Engine balance

$$Q_H = W_{\text{out}} + Q_C; \eta = W_{\text{out}}/Q_H.$$

KEY TAKEAWAY 2

Cooling and heating

$$Q_H = Q_C + W_{\text{in}}; \text{COP}_R = Q_C/W_{\text{in}} \text{ and } \text{COP}_{\text{HP}} = Q_H/W_{\text{in}}.$$

KEY TAKEAWAY 3

Physical limits

The reversible temperature bound is an upper limit; real cyclic devices perform below it.

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 →](#)

ANSWER KEY • CHECK AFTER ATTEMPTING

Solutions and Explanations

Check your reasoning and the energy balance, not only the final number.

WARM-UP • ACTIVITY 1**Recall Activity 1**

Three arrows: Q_H in, W_{out} out, Q_C out.

WHY IT WORKS The working fluid returns to its original state after a cycle.

WARM-UP • ACTIVITY 2**Recall Activity 2**

Engine: work; refrigerator: cold-space heat removal; heat pump: warm-space heat delivery.

WHY IT WORKS Useful output depends on the device's job.

WARM-UP • ACTIVITY 3**Recall Activity 3**

A device receives 800 J from a hot source and rejects 600 J. Its work output is 200 J and efficiency is $200/800 = 0.25$, or 25%.

WHY IT WORKS First-law cycle balance gives work as the difference.

SOLUTIONS • GUIDED PRACTICE

PRACTICE 1**Worked Example**

$$W_{\text{out}} = 300 \text{ J}; \eta = 30\%.$$

WHY IT WORKS Compute $1,000 - 700$, then divide work by $1,000 \text{ J}$.

PRACTICE 2**Guided Problem**

$$Q_{\text{H}} = 600 \text{ J}; \text{COP}_{\text{R}} = 3; \text{COP}_{\text{HP}} = 4.$$

WHY IT WORKS Add 450 and 150 ; use each useful heat transfer over 150 J .

PRACTICE 3**Independent Problem**

No: 50% exceeds the 40% reversible limit.

WHY IT WORKS A real engine cannot exceed the reversible bound between the same reservoirs.

SOLUTIONS • CONFIDENCE CHECK

QUICK CHECK 1

Energy balance

$$W_{\text{out}} = 270 \text{ J}; \eta = 270/900 = 0.30.$$

WHY IT WORKS Subtract 630 J from 900 J and divide by 900 J.

QUICK CHECK 2

Reversed cycle

$$Q_H = 800 \text{ J}; \text{COP}_R = 600/200 = 3; \text{COP}_{HP} = 800/200 = 4.$$

WHY IT WORKS The delivered heat includes cold-side transfer plus work.

QUICK CHECK 3

Temperature limit

$$\eta_{\text{Carnot}} = 1 - 300/600 = 0.50; \text{ a 60\% claim is impossible.}$$

WHY IT WORKS Use absolute reservoir temperatures and compare with the reversible upper bound.

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 Review the key ideas and examples again. Review Again →	 I Need More Practice Continue with additional practice for this topic. Go to Practice →	 I'm Ready Continue to the next recommended resource. Continue →
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RECOMMENDED LINKS

[Review this topic again →](#)[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](#)