PC.2.L1 - Solutions

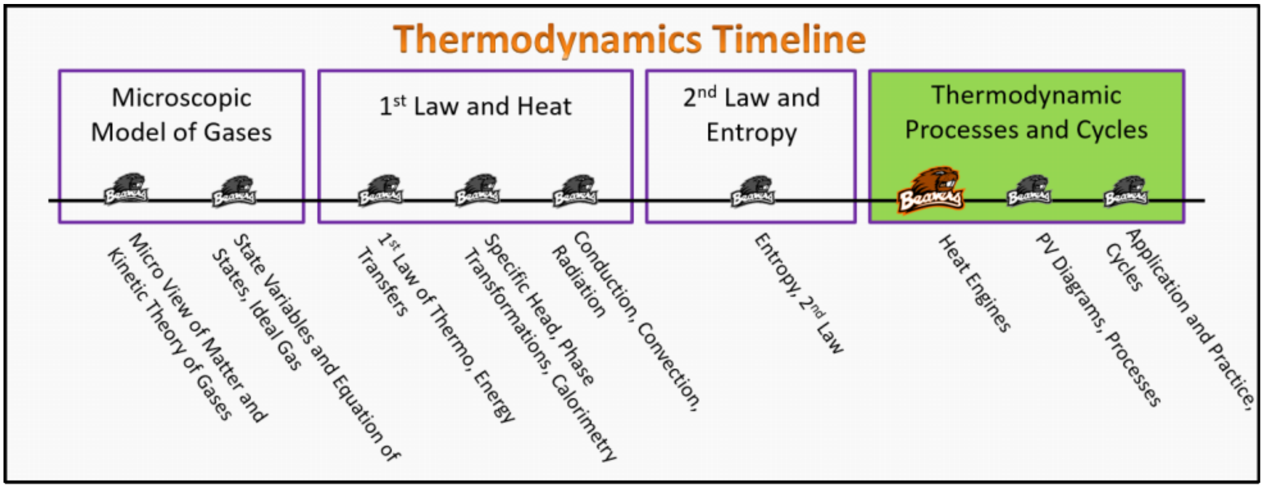
Monday, February 4, 2019 7:29 AM

# Thermodynamics

## Foundation Stage (PC.2.L1)

**Lecture 1**

**Heat Engines**




**Textbook Chapters** (* Calculus version)

- **BoxSand** :: KC videos ( Entropy and 2nd Law of Thermodynamics)
- **Knight** (College Physics : A strategic approach 3rd) :: 11.4 ; 11.5 ; 11.6
- ***Knight** (Physics for Scientists and Engineers 4th) :: 21.1 ; 21.2
- **Giancoli** (Physics Principles with Applications 7th) :: 15-5 ; 15-6

### Warm up

**PC.2.L1-1:**

**Description:** Application of 1st law.

**Learning Objectives:** [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

**Problem Statement:** A container of monatomic ideal gas is taken through two processes as follows: First the gas is compressed such that the work done on the gas is 10 J and 5 J of heat was removed during the compression. Second, the gas is then allowed to expand back to its original volume, pressure, and temperature. During the expansion, the gas does 10 J of work on the environment, and gains 5 J of heat.

**(a)** What is the change in thermal energy during the compression and expansion stages?

compression

$$\Delta E_{th} = W + Q$$

$$= 10J - 5J = +5J$$

expansion

$$\Delta E_{th} = -10J + 5J = -5J$$

**(b)** What is the change in thermal energy for the complete 2 stage cycle?

$$\Delta E_{tot} = +5J - 5J = 0$$

## Selected Learning Objectives

1. Coming soon to a lecture template near you.

## Key Terms

- Heat engine
- Heat pump
- Efficiency

## Key Equations

## Key Concepts

- Coming soon to a lecture template near you.

## Questions

### Act I: Thermo Laws and Sankey Diagrams

**PC.2.L1-2:**

**Description:** Identify which Sankey diagrams are possible. (4 minutes)

**Learning Objectives:** [1, 12, 13]

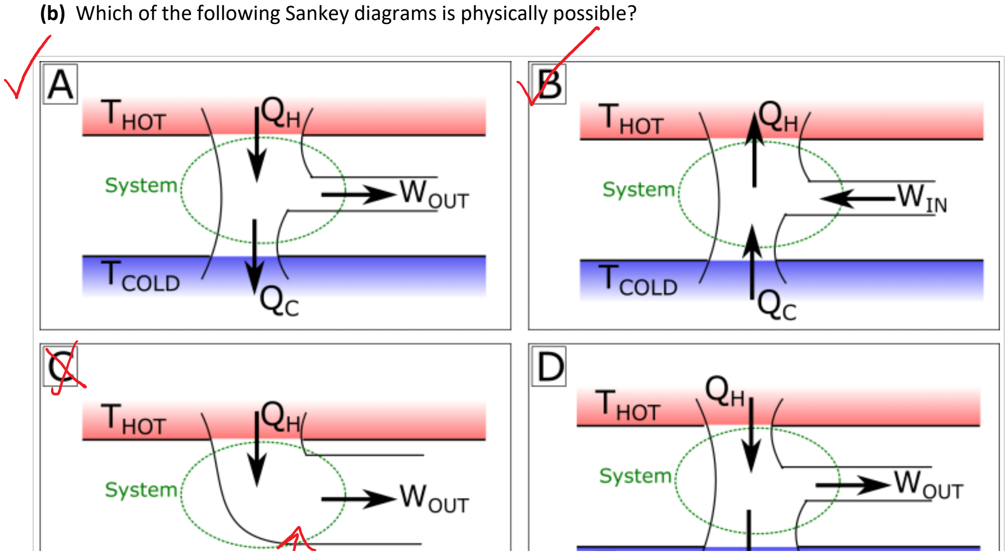
**Problem Statement:** Diesel engines are used to perform work.

**(a)** After a diesel engine has been running for a long time, what happens to the temperature of the engine over time?

(1) Roughly steady
(2) Increases
(3) Decreases

otherwise engine would melt!

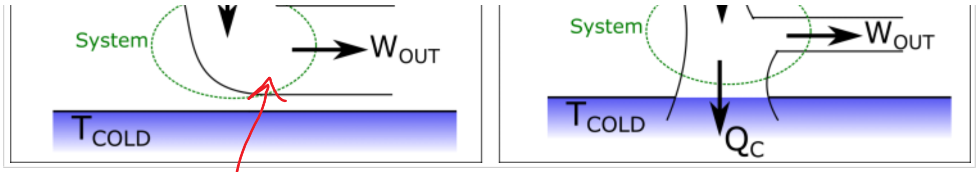
**(b)** Which of the following Sankey diagrams is physically possible?




$W_{in} + Q_{in} = W_{out} + Q_{out}$

$Q_{in} < W_{out} + Q_{out}$

$\Rightarrow$ energy not




$Q_{in} < W_{out} + Q_{out}$
$\Rightarrow$ energy not conserved!

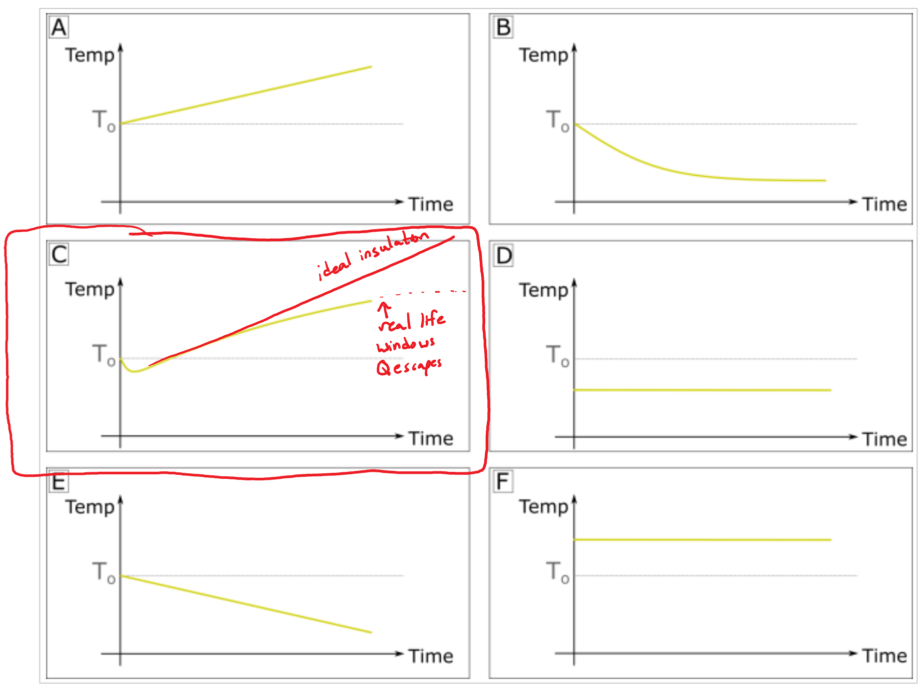
no reason for heat to flow

**PC.2.L1-3:**

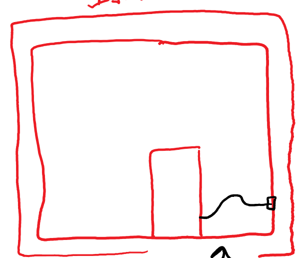
**Description:** Identify best graph of temperature vs time for open door of fridge. (4 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** On a particularly hot day you leave your refrigerator door open. Which of the following temperature vs time graphs would best represent the temperature of the room will be over the next couple of hours. Assume your kitchen is perfectly insulated and the temperature is being read right near the door of the fridge.




Isolated



electric work added,
$Q_{out} = 0$
$\Rightarrow E_{th} \uparrow$ forever

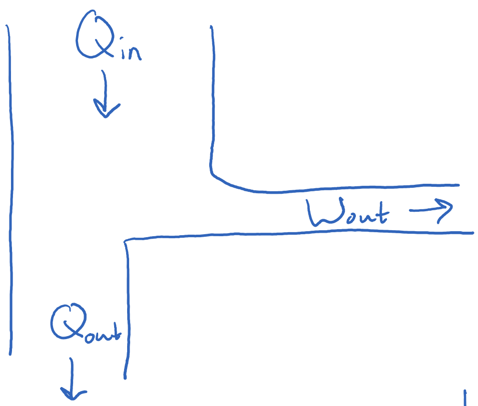
## Act II: Characterizing Heat Engines (Using 1st Law and Efficiency)

**PC.2.L1-4:**

**Description:** Calculate efficiency of heat engine. (6 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** A heat engine does 10 J of work and exhausts 15 J of waste heat during each cycle. What is the engine's thermal efficiency?




$$Q_{in} = Q_{out} + W_{out}$$

$$Q_{in} = 25\text{ J}$$

$$\text{eff.} = \frac{W_{out}}{Q_{in}} = \frac{10\text{ J}}{25\text{ J}} = 0.4 \Rightarrow 40\%$$

human body – 25%

your car – 20-25%

F1 race car – 50%

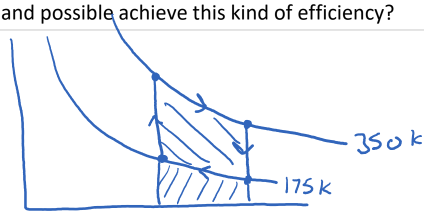
**PC.2.L1-5:**

**Description:** Given theoretical max efficiency, what is a reservoir temperature. (5 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** You wish to produce a heat engine that has a 50% efficiency. You can access water at 350 K from the local factory. What is the maximum temperature your cold reservoir could be and possible achieve this kind of efficiency?

$$\text{Max eff.} = 1 - \frac{T_C}{T_H}$$




$$0.5 = 1 - \frac{T_C}{350\text{ K}}$$

$$\frac{T_C}{350\text{ K}} = 0.5$$

$$T_C = (0.5)(350\text{ K}) = \boxed{175\text{ K}}$$

**PC.2.L1-6:**

**Description:** Calculate efficiency of heat engine. (6 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** A 60% efficient device uses chemical energy to generate 600 J of electric energy. A second device uses twice as much chemical energy to generate half as much electric energy. What is the efficiency of this second device?

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$$\text{eff.} = 0.6 = \frac{W_{1out}}{Q_{1in}} = \frac{600\,J}{?}$$

$$Q_{2in} = 2\,Q_{1in}$$

$$W_{2out} = \frac{1}{2} W_{1out}$$

$$\Rightarrow \text{eff}_2 = \frac{\frac{1}{2} W_{1out}}{2\,Q_{1in}} = \frac{1}{4}\frac{W_{1out}}{Q_{1in}} = \frac{1}{4}\text{eff}_1$$

$$\boxed{\text{eff}_2 = 15\%}$$

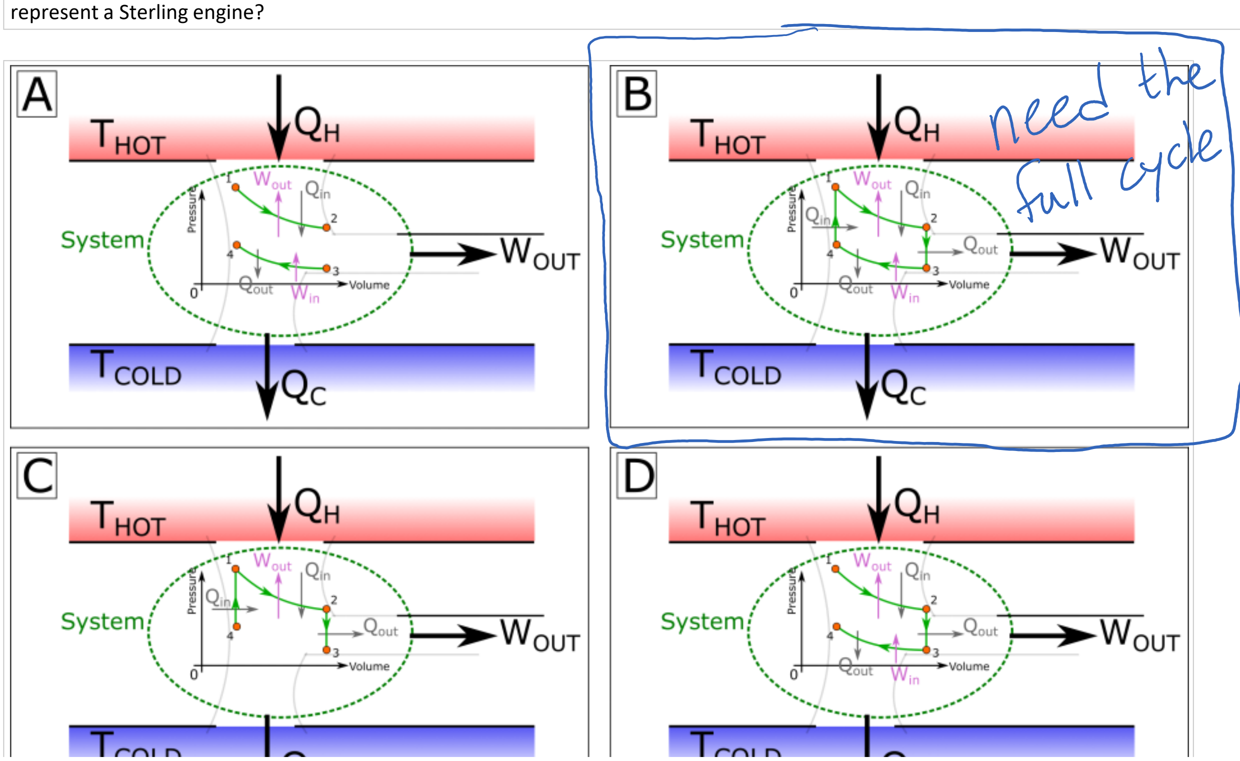
## Act III: Peering into the Black Box

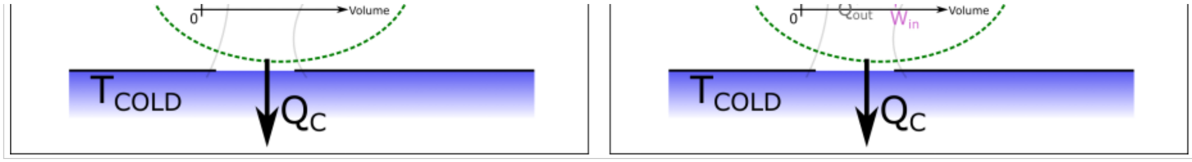
**PC.2.L1-7:**

**Description:** Identify which PV-Diagram could represent a heat engine. (3 minutes)

**Learning Objectives: [1, 12, 13]**

**Problem Statement:** Another type of heat engine is called a Sterling engine. Which one of the four Sankey diagrams could possibly represent a Sterling engine?






## Conceptual questions for discussion

1. Coming soon.

## Hints

**PC.2.L1-1**: No hints.

**PC.2.L1-2**: No hints.

**PC.2.L1-3**: No hints.

**PC.2.L1-4**: No hints.

**PC.2.L1-5**: No hints.

**PC.2.L1-6**: No hints.

**PC.2.L1-7**: No hints.