Thursday April 16

See the [*course webpage*] *for* ***slides****,*
video links*, and google docs* ***Q&A*** *links*

Topics for this Lecture:

- *Cycles*
- *Heat Engines*

- Assignment “13” due Friday
- Pre-class due 15min before usual class time
- Help Room: via Teams, 6-9pm Wed/Thurs, also via email on Wed/Thurs
- SI: via Teams
- Office Hours: via email (meisel@ohio.edu)

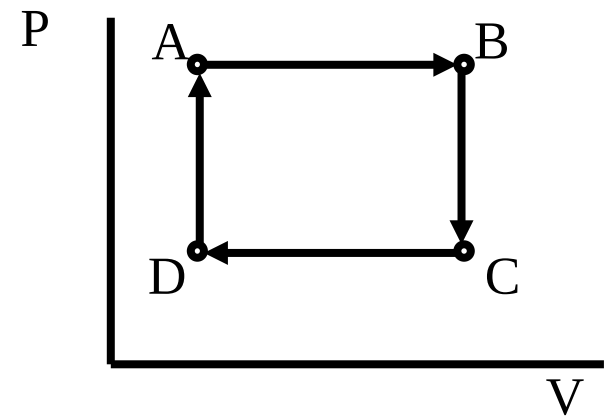
Heat engines:

- $Q_H = W + Q_C$
- Efficiency, $e = W/Q_H = (Q_H-Q_C)/Q_H$
  $= (1-Q_C/Q_H)/1$
- Max heat engine efficiency, is the Carnot efficiency, $e_{Carnot} = 1-(T_C/T_H)$
- Coefficient of performance, COP, $COP = Q_H/W$

“INFORMATION FOR EXAM 3” is posted on LON-CAPA

Exam 3, again in Lon-Capa, will open at Noon Monday April 20th and close at 6pm on Tuesday April 21st. Once started, you have 90min to complete the exam. The 90min must fully fall within this time window.

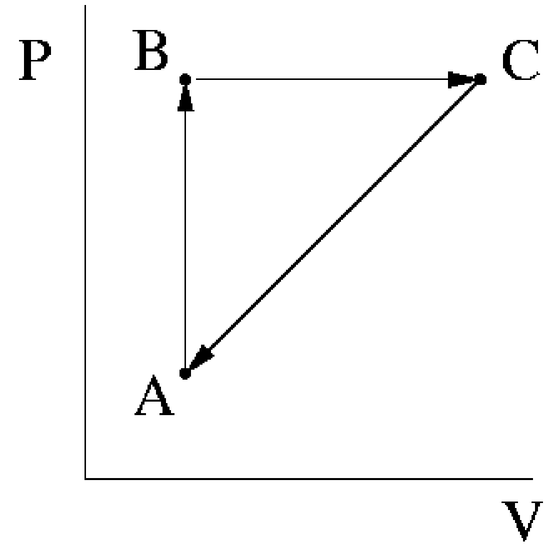
Cycles: Transitions that form a loop in a PV diagram



- For a full cycle: State A->B->C->D->A
  - $\Delta U_{net} = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CD} + \Delta U_{DA} = 0$
  - $W_{net} = W_{AB} + W_{BC} + W_{CD} + W_{DA}$
  - $Q_{net} = Q_{AB} + Q_{BC} + Q_{CD} + Q_{DA}$
- For example, for the cycle A->D on the right
  - $\Delta U_{net} = 0$, as for all cycles
  - $W_{net} > 0$, since the area under A->B is greater than the area under C->D
  - From the first law, $\Delta U = Q - W = 0$. So $Q_{net} = W_{net} > 0$
- If the arrow direction were reversed (i.e. A->D->C->B->A), the signs would all flip! I.e. $W_{net} = Q_{net} < 0$

In this picture, Q_{AB} is positive and ΔU_{BC} is positive.
What is the sign of of ΔU_{CA}?

(A) positive (B) negative (C) zero



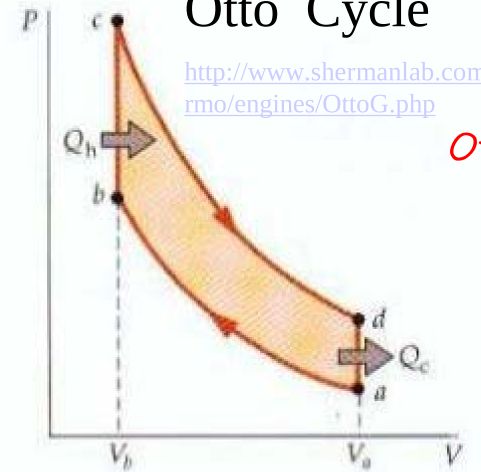
1. Cycle: $\Delta U_{net} = 0 = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CA} = 0$
2. $\Delta U_{AB} = Q_{AB} - W_{AB}$
   1. Area under A->B is zero, so $W_{AB} = 0$
   2. So, $\Delta U_{AB} = Q_{AB}$, which we're told is >0.
3. We're told $\Delta U_{BC} > 0$
4. Since $\Delta U_{net} = 0$, but $\Delta U_{AB} > 0$ and $\Delta U_{BC} > 0$, ΔU_{CA} =must be <0.

Examples of common engine cycles:

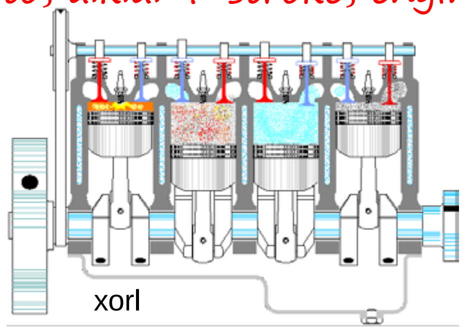
For cool animations, see: http://www.animatedengines.com/

Otto Cycle

http://www.shermanlab.com/science/physics/thermo/engines/OttoG.php

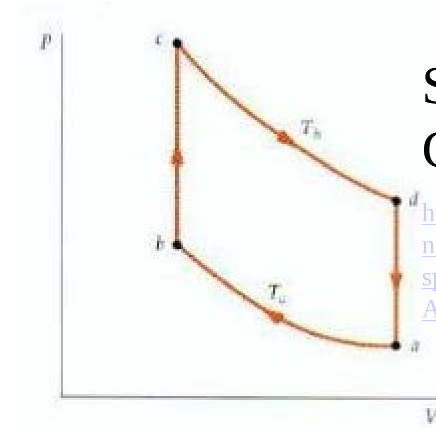


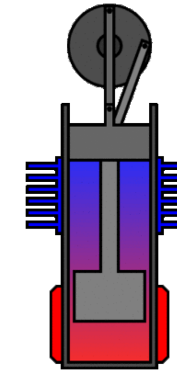
Otto, a.k.a. 4-stroke, engine:



Stirling Cycle

http://www.stirlingengine.com/Displacer-Anim.adp

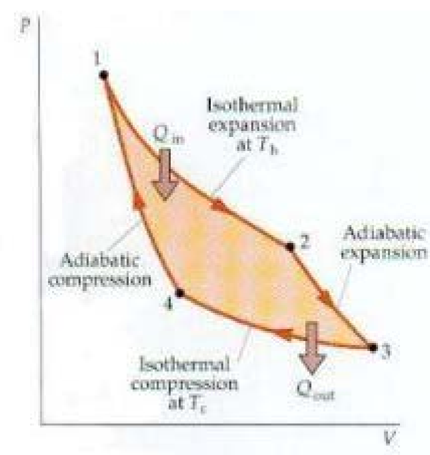




YK Times

Carnot Cycle

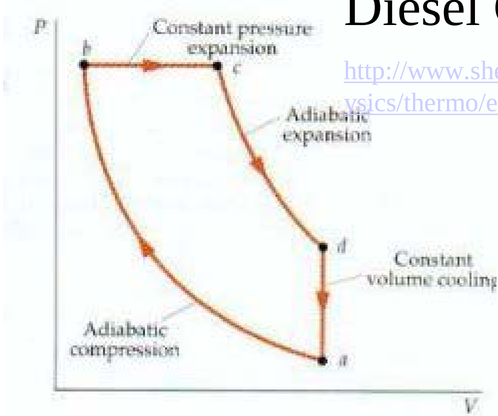
http://www.rawbw.com/~xmwang/myGUI/CarnotG.html



Most efficient engine type powered by two heat reservoirs (one hot & one cold, e.g. flame & a stream).

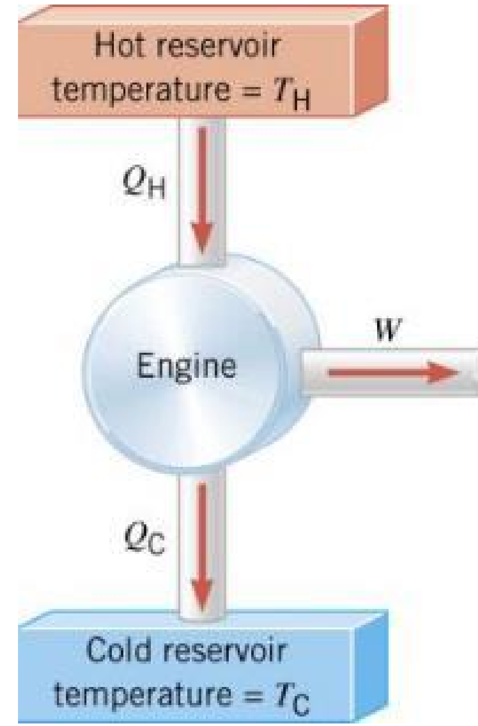
Diesel Cycle

http://www.shermanlab.com/science/physics/thermo/engines/DieselG.php



Similar to Otto cycle, but compression provides heat for fuel ignition (which leads to expansion). Can be 2 or 4 stroke.

Heat Engines



- *Heat Engine*: generating work from a temperature difference between a hot and a cold reservoir.
  - E.g. the High-T reservoir could be created by burning fuel & the Low-T reservoir could be the ambient air
- This is accomplished by heat transfer between the reservoirs and the engine.
- The heat engine can be reversed; where work is used to create a temperature difference.

- Heat engines operate in a cycle: $\Delta U = 0$
  - From the 1st law of thermodynamics: $\Delta U = Q - W$ ….so for the engine, $Q_{cycle} = W_{cycle}$
  - The high-T reservoir is adding heat for the cycle, whereas the low-T reservoir is removing heat, so $Q_{cycle} = Q_H - Q_C$
  - Therefore, $W = Q_H - Q_C$ (this is more commonly written as: $Q_H = W + Q_C$)
- Efficiency is what you get out over what you put in: $e = W/Q_H = (Q_H - Q_C)/Q_H = 1 - Q_C/Q_H$

What is the efficiency of a heat engine that pulls 8000J from the hot reservoir and expels 6000J in the form of exhaust?

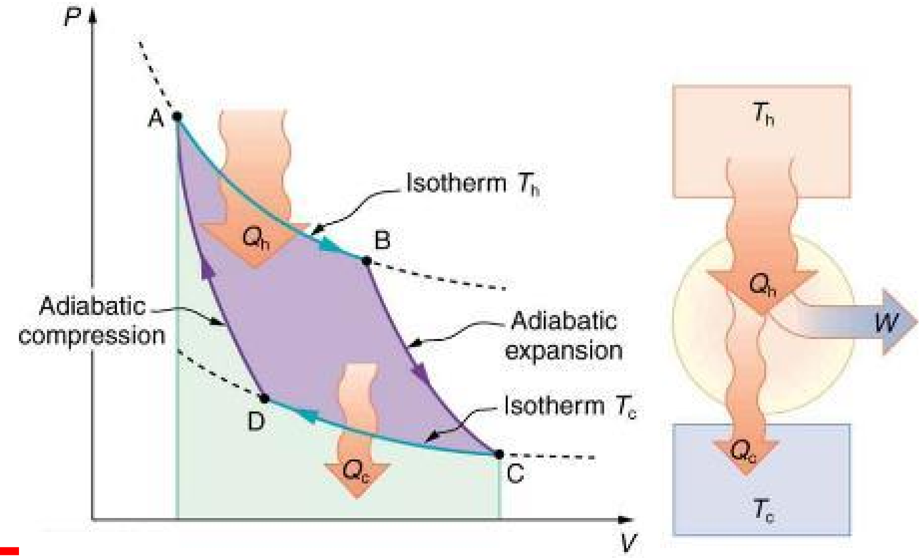
(A) 10%　　(B) 25%　　(C) 33%　　(D) 125%

1. Efficiency = (What you get out)/(what you put in)
2. $e = W/Q_H$
3. Work you get out is the difference between head added & heat removed.
4. $W = Q_H - Q_C$
5. $e = (Q_H - Q_C)/Q_H = (8000J - 6000J)/(8000J) = 0.25 = 25\%$

Can see (also from the form: $e = 1 - Q_C/Q_H$) that minimizing the ratio of heat removed to heat added is required to maximize efficiency.
The amount of heat added & heat removed depends on the type of transition that's doing the adding/removing.

Carnot Engine: Maximally efficient heat engine

- For the best-possible heat engine, the disorder of the system & surroundings doesn't increase when transferring heat. (This is practically impossible, but we can imagine it).
- Also, the hot & cold reservoirs are infinite and no amount of adding or removing heat changes the reservoirs' temperatures.
- For this case, the Carnot Engine,



$$\frac{Q_C}{Q_H} = \frac{T_C}{T_H} \qquad e_{Carnot} = 1 - \frac{T_C}{T_H}$$

- You can never have a larger efficiency than this for a heat engine!
- *Here **<u>temperature must be in Kelvin</u>**

Because of the 3rd law of thermodynamics, you can't make T_C=0, so you can't have a perfectly efficient engine.

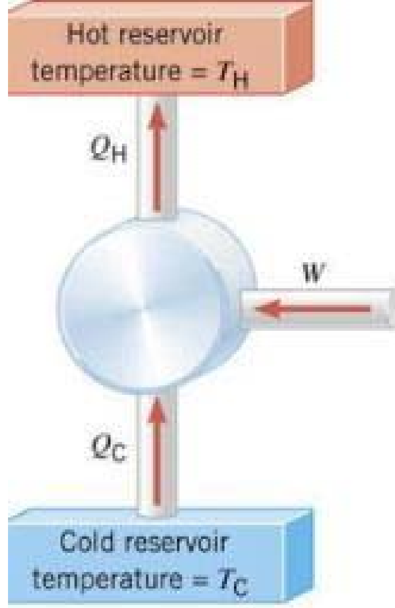
Your crazy uncle fancies himself an inventor and claims to have created an engine that draws heat from a reservoir at 375K, does 5000J of work per second and expels 4000J of work per second into a cold reservoir of 225K. Is this possible?

(A) yes (Invest!)

(B) no (Tell him to go away)

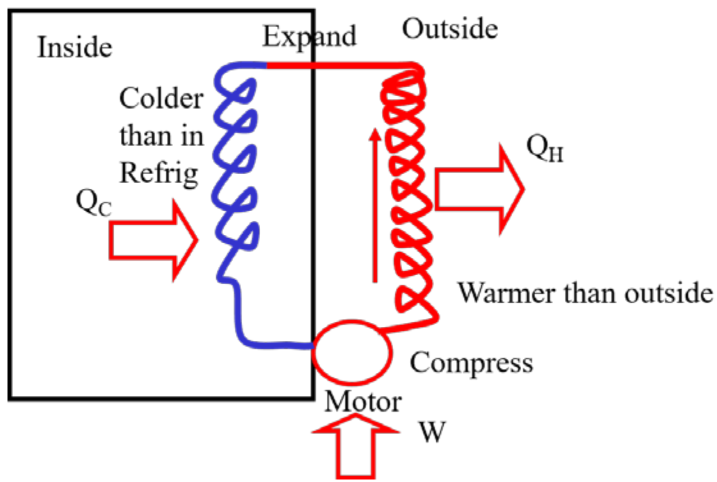
1. Claimed efficiency = $e = W/Q_H = W/(W+Q_C)$ = 5000J/(5000J+4000J) = 0.56
2. Carnot efficiency = $e_{Carnot} = 1 - T_C/T_H$ = 1 - 225K/375K = 0.4
3. The claimed efficiency is better than the theoretical maximum. It is not possible.

Refrigerator: Reversed heat engine (to cool) 📖 Sect 15.10



Refrigeration Process

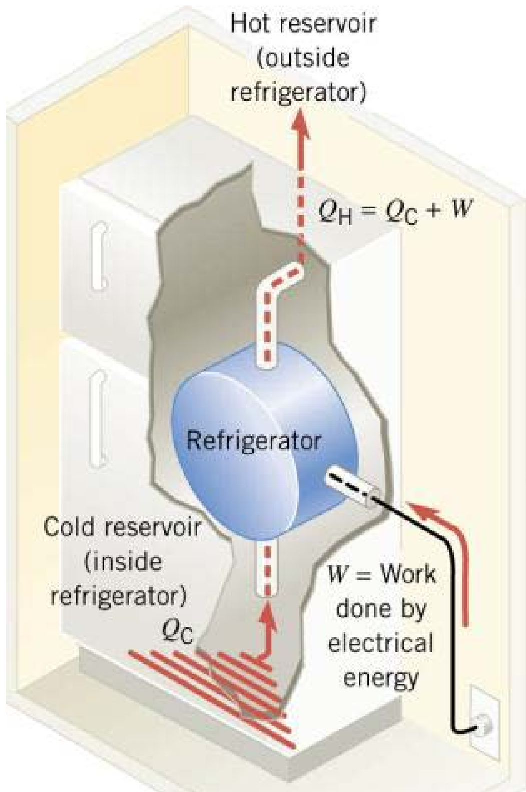
- We can reverse our heat engine, putting work in to create a temperature difference. This can be a refrigerator.
  - This works by compressing a fluid (a.k.a. refrigerant), which heats it. That heat is given-off to the environment (on the back of your refrigerator). It is then allowed to expand, cooling it (just before it enters the fridge). Heat is then transferred from the stuff in the fridge to the cold tubes with the cold refrigerant.
- As before: $Q_H - Q_C = W$
- Now, how well your refrigerator is performing depends on how much it is cooling divided by how much work you put it:
  - Coefficient of performance = $COP_R = Q_C/W$
  - Rewritten: $COP_R = (Q_C/Q_H)/(1-Q_C/Q_H)$
- For a perfect (a.k.a. Carnot) refrigerator:
  - $COP_{R,Carnot} = (T_C/T_H)/(1-T_C/T_H)$



A refrigerator removes 60000J of heat from hot food placed inside. The COP is 3.0. We eventually want to know the amount of heat exhausted into the room. First, though, which quantity does the 60000J represent?

(A) Q_C (B) Q_H (C) W

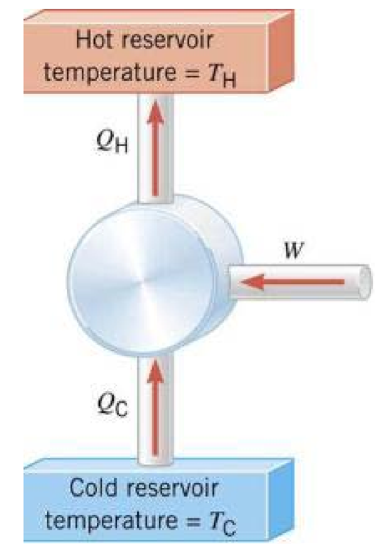
60000J represents the amount of energy which must be removed from the cold reservoir.



A refrigerator removes 60000J of heat from hot food placed inside. The COP is 3.0. What is the amount of heat exhausted to the room? (I.e. moved into the hot reservoir)

(A) 20,000J (B) 60,000J (C) 80,000J (D) 180,000

1. The coefficient of performance for a refrigerator is the ratio of how much heat you remove divided by how much work you put in to remove that heat: $COP = Q_C/W$
2. $3.0 = (60{,}000\ J)/W$
3. $W = (60{,}000J)/3 = 20{,}000\ J$
4. $Q_H = Q_C + W = 60{,}000\ J + 20{,}000\ J = 80{,}000J$



Refrigeration Process

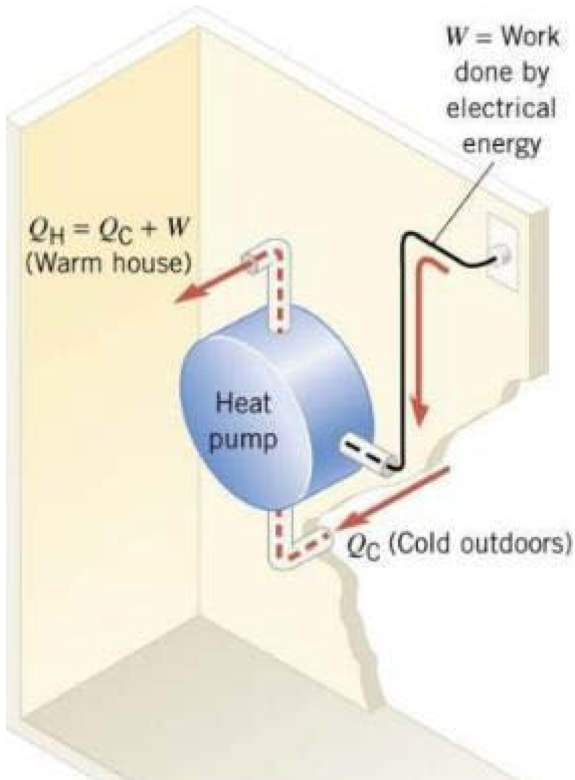
A refrigerator removes 60000J of heat from hot food placed inside. The COP is 3.0. If the power of the motor is 200W, what is the minimum time to cool the food?

(A) 100s   (B) 200s   (C) 300 s

1. We just found that the fridge requires 20,000J of work to cool the food: W = 20,000J
2. Power = Energy/Time = 200W = (20,000J)/(Time)
3. Time = (20,000J)/(200J/s) = 100s

Heat Pump: Reversed heat engine (to heat) 📖 Sect 15.10

- We can reverse our heat engine, putting work in to create a temperature difference. This can be a heater.
- As before: $Q_H - Q_C = W$
- Your heat pump performance depends on how much heat you're getting out compared to how much work you're putting in
  - Coefficient of performance = $COP_H = Q_H/W$



Each drawing shows a hypothetical heat engine or a hypothetical heat pump and shows the corresponding heats and works. Only one of these scenarios is physically possible. Which is it?

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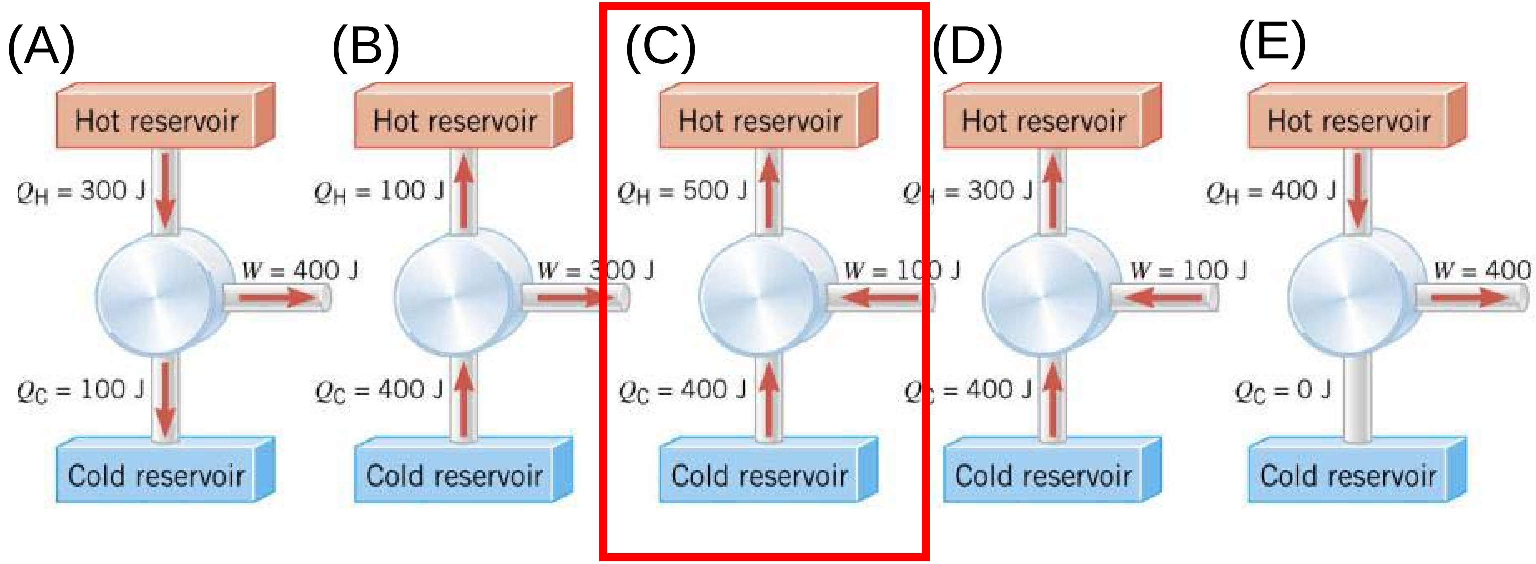

1. Energy is conserved: what goes in has to equal what comes out
2. There is no such thing as a perfect engine.

   For (E), all of the input heat can’t be directly converted to work.

Heat Engines, Heat Pumps, & Refrigerators: Summary

Device	Basic Concept	What it provides	What we pay for/put in	How well the device is doing its job
Heat Engine	A natural flow of heat (hot to cold) is used to do work on surroundings.	Net Work: W_{net}	Heat from high-T reservoir: Q_H	$0 < e = W_{net}/Q_H < 1$ $(e_{Carnot} = 1 - T_C/T_H)$
Heat Pump	An un-natural flow of heat (cold to hot) is created by work from surroundings.	Adds heat: Q_H	Work from surroundings: W_{net}	$COP_H = Q_H/W_{net}$ $(COP_{H,Carnot} = 1/(1-T_C/T_H))$
Refrigerator	An un-natural flow of heat (cold to hot) is created by work from surroundings.	Removes heat: Q_C	Work from surroundings: W_{net}	$COP_R = Q_C/W_{net}$ $(COP_{R,Carnot} = 1/(T_H/T_C - 1))$