Physics 141.
Lecture 26.

We are almost there!

Physics 141.
Lecture 26.

- Course Information.
- Quiz
- Continued discussion of Chapter 13:
  - The second law of thermodynamics and the flow of heat.
  - Engines and heat pumps.
  - Efficiency

Physics 141.
Course Information.

- Optional homework set # 11 is due on Tuesday 12/13 at noon.

- There will be a post-test on Tuesday 12/13 morning at 8.45 am. This test will not impact your grade but will provide you with feedback on the areas in which you still show weakness. It will help you focus your effort during finals week.

- On Tuesday 12/13 during our last lecture period:
  - I will talk about the Physics of Flying – how what we learned in Physics 141 allows you to understand the physics of flight. Note: you will not be tested on the Physics of Flying on the final exam.
  - Attendance is completely optional!

Physics 141. Course Information.

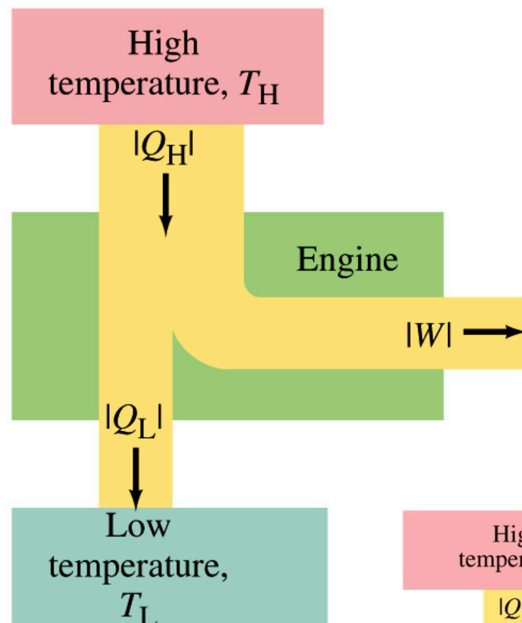
- You will receive an email with your grade on Exam # 3 on Monday 12/12.
- I will also send a summary of all your grades in the course early next week, including the results of a calculation that will show what grade you need to get on the final exam to get an A-, a B-, and a C- in this course.
- The final exam will take place on Tuesday 12/20 between 4 pm and 7 pm in Hoyt. The material to be covered is Chapter 1 - 13 + equilibrium.
- Extra office hours will be scheduled before the final exam. Details will be announced via email.

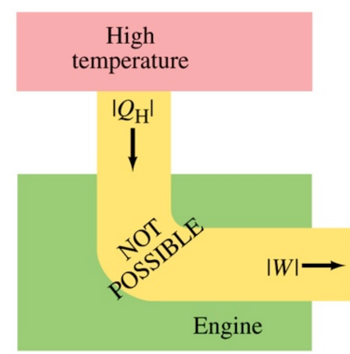
The Personal Response System (PRS). Quiz Lecture 26.

The second law of thermodynamics. Heat Flow.

- There are several different forms of the second law of thermodynamics:
  - It is not possible to completely change heat into work with no other change taking place.
  - Heat flows naturally from a hot object to a cold object; heat will not flow spontaneously from a cold object to a hot object.

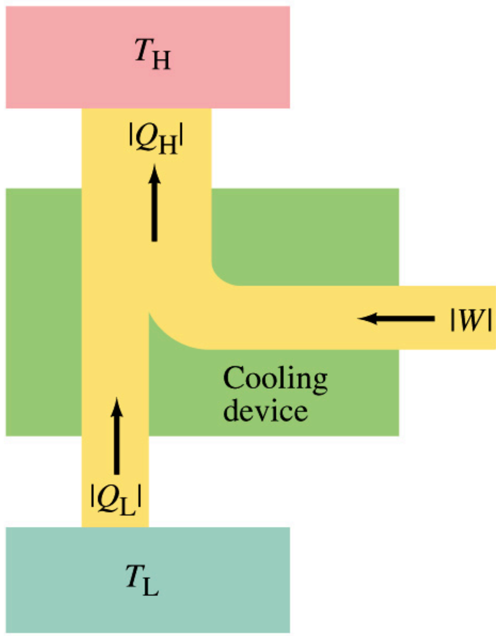
- Many naturally processes do not violate conservation of energy when executed in reverse, but would violate the second law.





The second law of thermodynamics. Heat Pumps.

- In many cases (heat engines), the conversion of flow of heat to work is the primary purpose of the engine (e.g. the car engine).
- In several other applications (heat pumps), work is converted to a flow of heat (e.g. air conditioning).

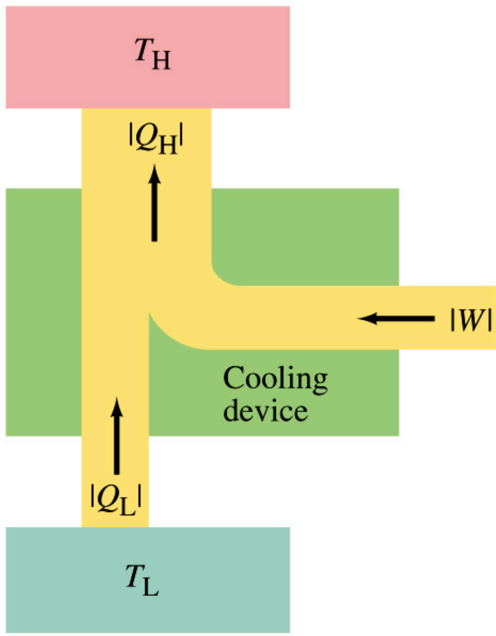


Second Law of Thermodynamics. Heat Pumps.

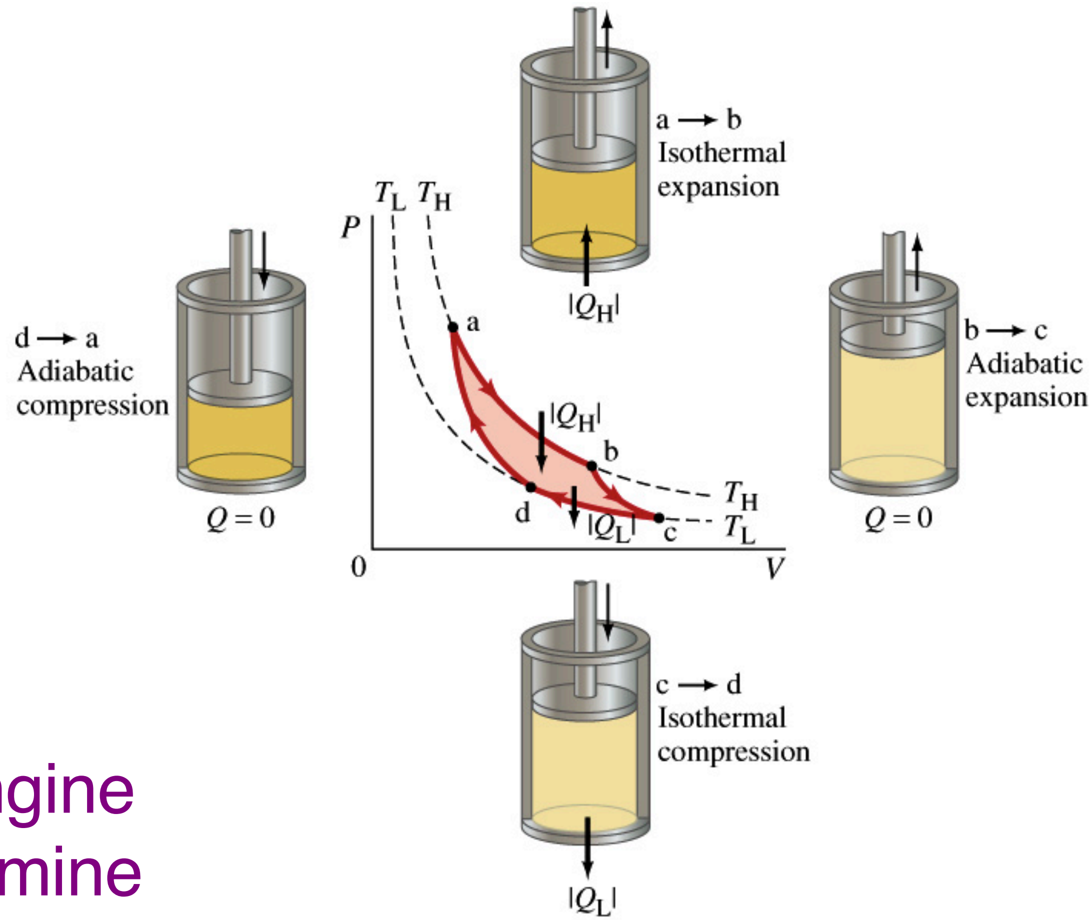
- In a heat pump we do work to move heat from a cold reservoir to a hot reservoir (note: we never have to do work to make heat flow the other way).

- The performance of a heat pump is usually specified by providing the coefficient of performance *K*:

$$K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$



The second law of thermodynamics.
The Carnot cycle.

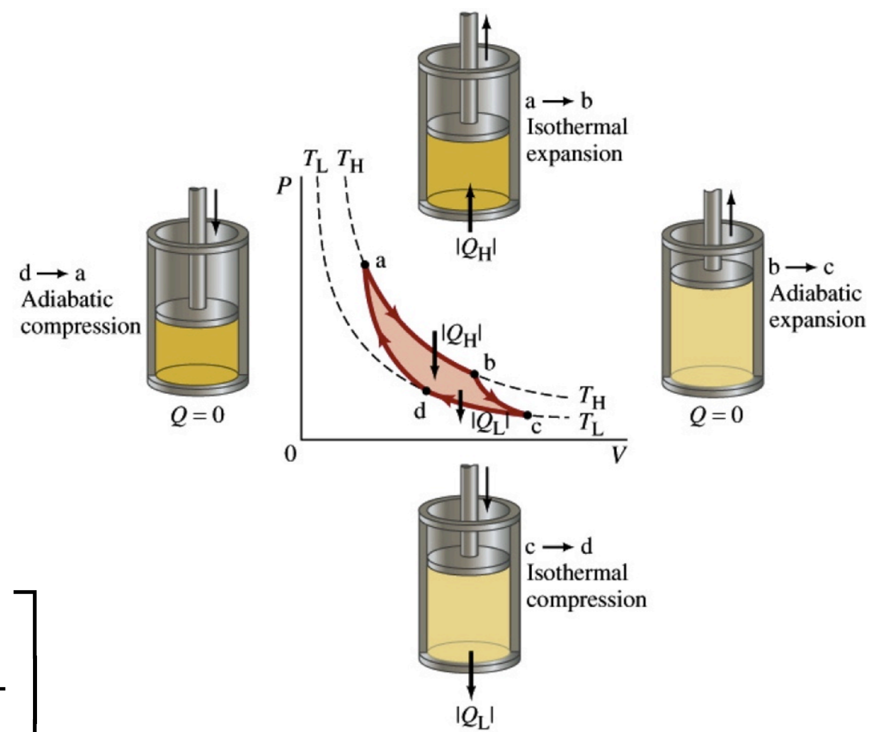


A "perfect" engine used to determine the limits on efficiency.

The second law of thermodynamics. The Carnot cycle.

- Step 1: a to b.
  - The gas is in contact with a heat bath at temperature T_H and weight is removed from the piston.
  - The gas expands, while maintaining a constant temperature (the change in the internal energy is thus equal to 0 J).
  - Using the first law of thermodynamics we see that

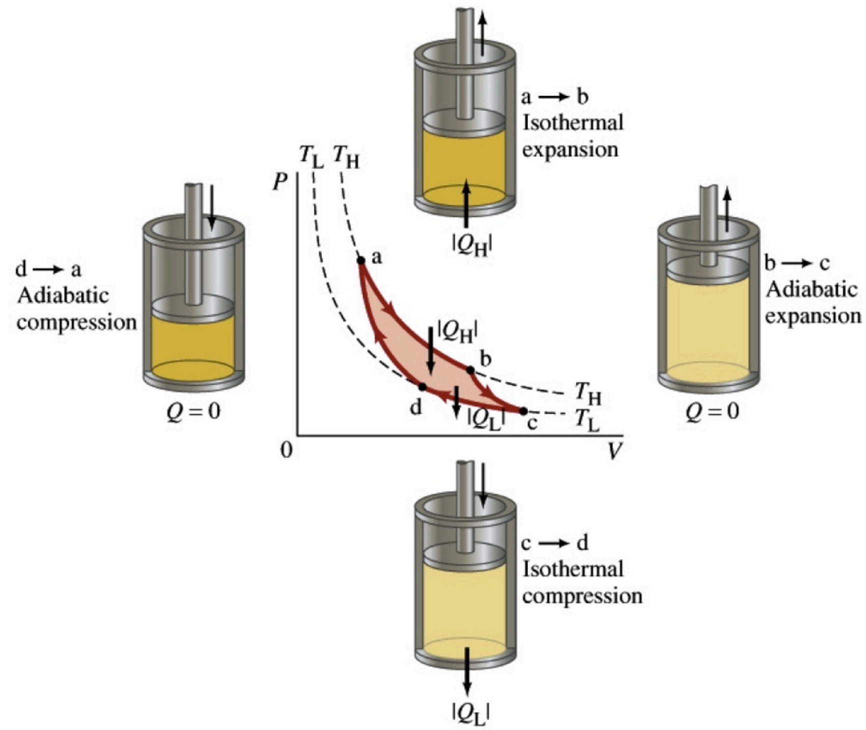
$$\left|Q_H\right| = \left|W_H\right| = NkT_H \ln\left[\frac{V_b}{V_a}\right]$$



The second law of thermodynamics. The Carnot cycle.

- Step 2: b to c.
  - The gas is isolated from the environment and some more weight is removed from the piston.
  - The gas expands and during the adiabatic expansion, the temperature of the gas will decrease.
  - For adiabatic expansion pV^{γ} is constant, and we can thus related state b to state c:

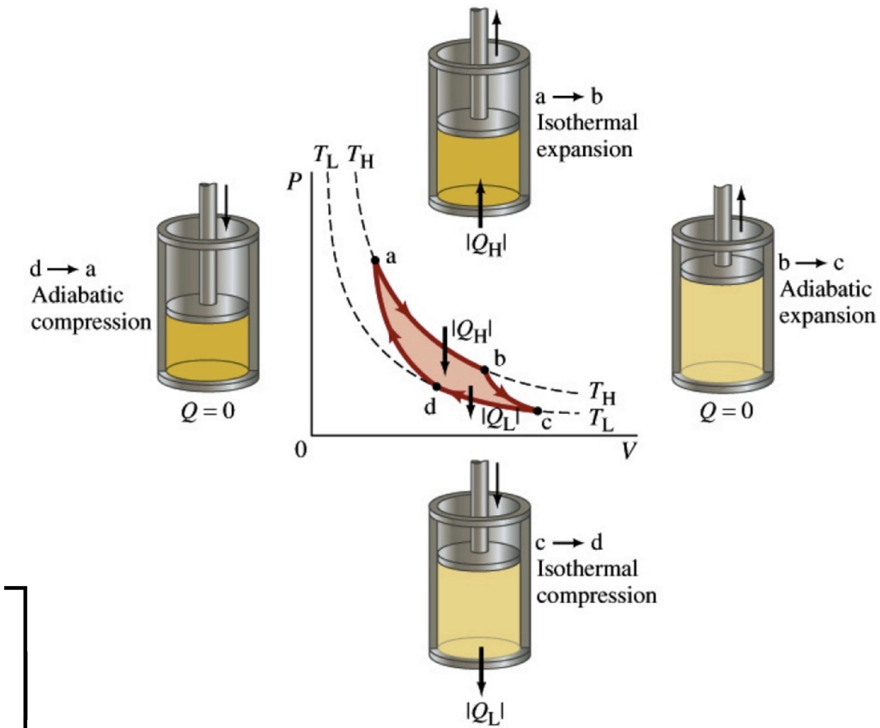
$$T_H V_b^{\gamma-1} = T_C V_c^{\gamma-1}$$



The second law of thermodynamics. The Carnot cycle.

- Step 3: c to d.
  - The gas is in contact with a heat bath at temperature T_C and weight is added to the piston.
  - The gas is compressed, while maintaining a constant temperature (the change in the internal energy is thus equal to 0 J).
  - Using the first law of thermodynamics we see that

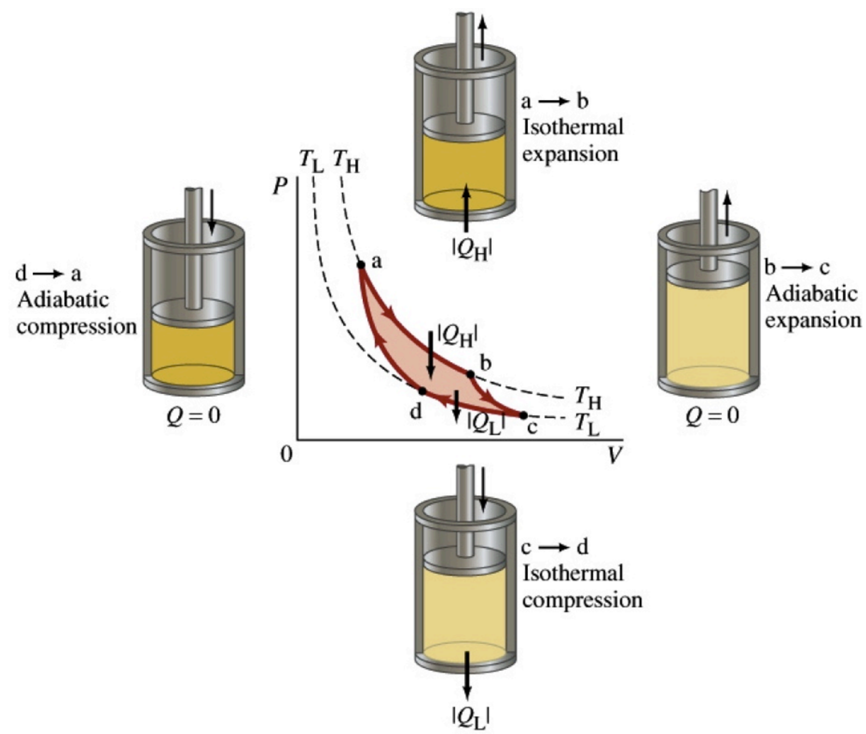
$$\left|Q_C\right| = \left|W_C\right| = NkT_C \ln\left[\frac{V_c}{V_d}\right]$$



The second law of thermodynamics. The Carnot cycle.

- Step 4: d to a.
  - The gas is isolated from the environment and some more weight is added to the piston.
  - The gas is compressed and during the adiabatic compression, the temperature of the gas will increase.
  - For adiabatic expansion pV^{γ} is constant, and we can thus related state b to state c:

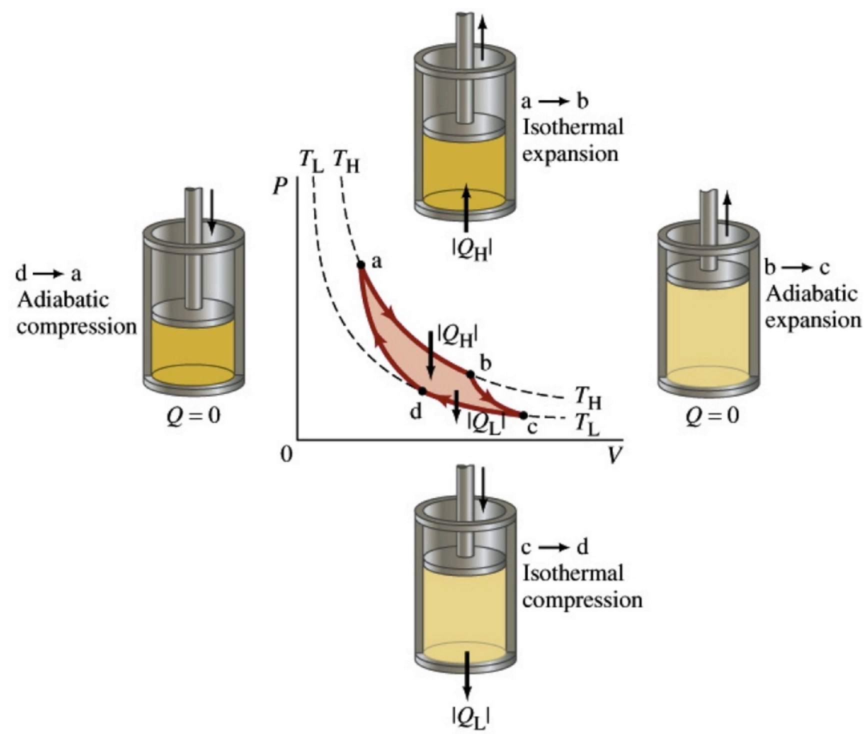
$$T_H V_a^{\gamma-1} = T_C V_d^{\gamma-1}$$



The second law of thermodynamics. The Carnot cycle.

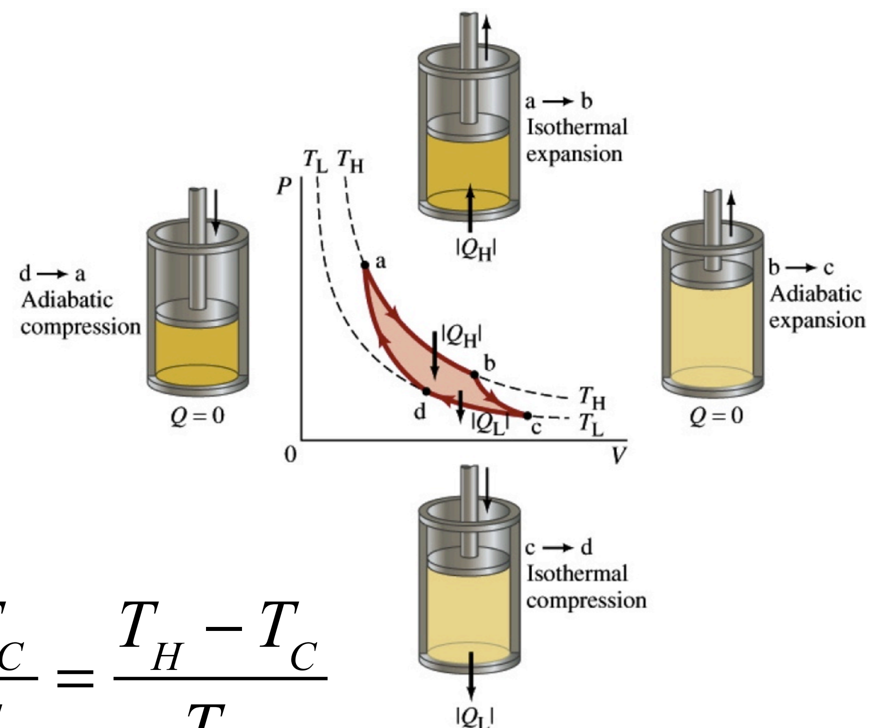
- The adiabatic expansion and compression steps can be used to show that $V_b/V_a = V_c/V_d$.
- This relation between the volumes is very useful since it allows us to determine the ratio between the heat flows:

$$\frac{|Q_H|}{|Q_C|} = \frac{T_H \ln\left[\frac{V_b}{V_a}\right]}{T_C \ln\left[\frac{V_c}{V_d}\right]} = \frac{T_H}{T_C}$$



The second law of thermodynamics. The Carnot cycle.

- The efficiency of the Carnot cycle can now be determined.
- Note that the work done by the Carnot engine is the difference between the heat extracted from the hot reservoir and the heat dumped in the cold reservoir:



$$e = \frac{|W|}{|Q_H|} = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{T_C}{T_H} = \frac{T_H - T_C}{T_H}$$

The second law of thermodynamics. The Carnot cycle.

- If we look at the efficiency of the Carnot cycle:

$$e = \frac{T_H - T_C}{T_H}$$

you see that the efficiency improves when the temperature difference between the hot and the cold bath increases. This is why it sometimes pays to increase the cooling of your engine!

- Carnot's theorem tells us that no real engine can have an efficiency more than that of the Carnot engine.

Physics 141.
Do you violate the second law?

- During the past 4 months, your brain hopefully has absorbed much of what I have covered, and concepts associated with mechanics should be in a much more ordered state in your brain on December 20 compared to their order on September 1.

- Did you violate the second law by going from disorder to order?

- Not if you include the disorder you dumped into your environment due to sweating over the exams and homework assignments. If you include that disorder, this course has a resulted in a greater disorder in our Universe (since clearly the impact of Physics 141 is irreversible).

Physics 141.
You are almost free (and so am I)!