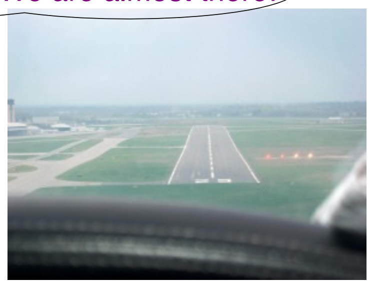
Physics 141.
Lecture 25.

We are almost there!



1

Thermodynamic at work.

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Physics 141.
Lecture 25.

- Course Information.
- Student Course Opinion Questionnaires.
- Quiz.
- Continue our discussion of Chapter 13:
  - Work done on/by and heat added to/removed from the ideal gas.
  - Engines and heat pumps.
  - Efficiency

3

Physics 141.
Course information.

- The optional homework (set # 11) is due on Friday December 15 at noon.
- To calculate the final homework grade, I remove the lowest homework grade and then take the average of the remaining 10 homework grades. If you are happy with homework grades 1 – 10, you can consider homework 11 as optional.
- Any regrade requests for Exam # 3 must be submitted to me today, following the guidelines listed in my email on Monday December 11.

Physics 141.
Course Information.

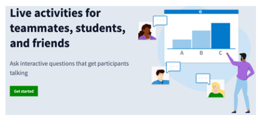
- I also send a summary of all your grades in the course on Wednesday 12/13, including the results of a calculation that will show what grade you need to get on the final exam to get an A-, a B-, and a C- in this course.
- The final exam will take place on Wednesday 12/20 at 4 pm in Hoyt. The exam will take 3 hours and cover all the material discussed in Phy 141, except the error analysis.
- Extra office hours will be scheduled before the final exam. Details will be announced via email.

Student Course Opinion Questionnaires.

- At this time of the year, the University asks each student to complete an on-line survey about the courses he/she is enrolled in.
- This survey is used both at the College level and at the Departmental level to monitor the teaching effectiveness of our faculty.
- You received an email this week from the Dean's office with the proper URL to access the on-line survey.
- I will not see the responses until after the grades have been handed in, so your response may not benefit you directly, but the responses of previous students have shaped your experience in Physics 141.
- If 95% of the Physics 141 students participate in the survey by Thursday 12/14, **everyone will receive 5% bonus points on the final exam**.

Quiz lecture 25.
PollEv.com/frankwolfs050

- The quiz today will have four questions.
- I will collect your answers electronically using the Poll Everywhere system.
- You have 30 seconds to answer each question.



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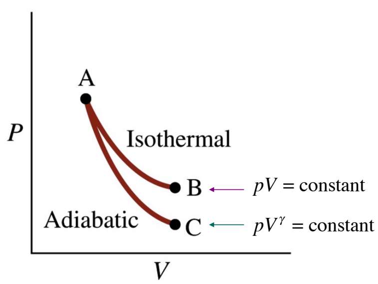
Processes relevant for our calculating the efficiency of engines.



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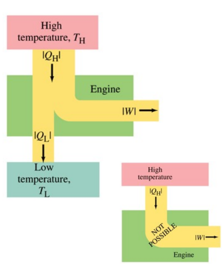
The second law of thermodynamics. Heat flow.

- 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.



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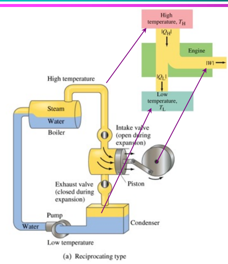
The second law of thermodynamics. Heat engines.

- Most engines rely on a temperature difference to operate.
- Let's understand why:
  - The steam pushes the piston to the right and does work on the piston: $W_{in} = NkT_{in} \ln[V_{in}/V_{out}]$
  - To remove the steam, the piston has to do work on the steam: $W_{out} = NkT_{out} \ln[V_{out}/V_{in}]$
  - If $T_{in} = T_{out}$: $W_{in} + W_{out} = 0$ (no net work is done).
  - In order to do work $T_{in} > T_{out}$ and we must thus cool the steam before compression starts.



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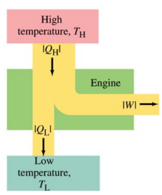
The second law of thermodynamics. Heat engines.

- The efficiency of a heat engine is defined as

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

- The work done and the heat extracted are usually measured per engine cycle.
- Since the heat flow to the low temperature reservoir can never be 0 J (this would violate the second law), the efficiency e can never be 100%.



Note: the cost of operation does not only depends on the cost of maintaining the high temperature reservoir, but may also include the cost of maintaining the cold temperature reservoir.

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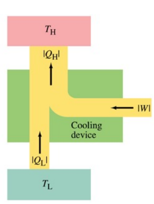
The second law of thermodynamics. Heat pumps.

- 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).



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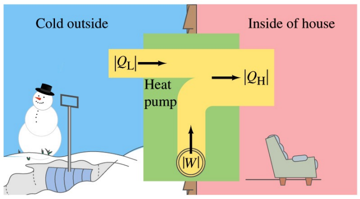
The second law of thermodynamics. Heat pumps.



Note: You usually pay for the work done but not for the heat extracted from the outside. You can thus get more energy than what you pay for!

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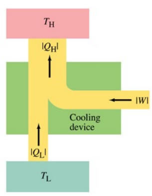
The second law of thermodynamics. Heat pumps.

- 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:

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



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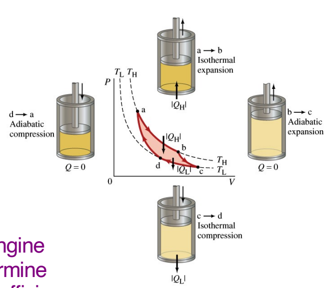
The second law of thermodynamics. The Carnot cycle.



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

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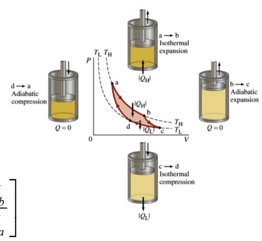
The second law of thermodynamics. The Carnot cycle.

- 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

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



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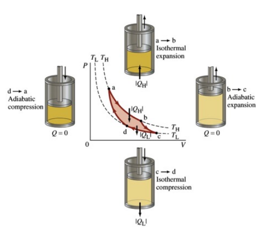
The second law of thermodynamics. The Carnot cycle.

- 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:

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



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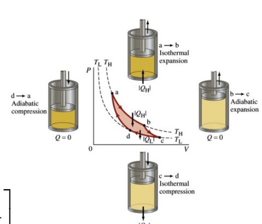
The second law of thermodynamics. The Carnot cycle.

- 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

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



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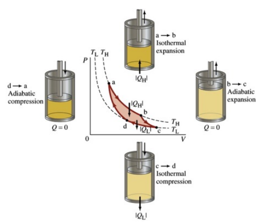
The second law of thermodynamics. The Carnot cycle.

- 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:

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



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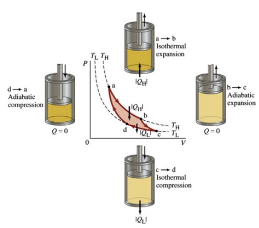
The second law of thermodynamics. The Carnot cycle.

- 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:

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



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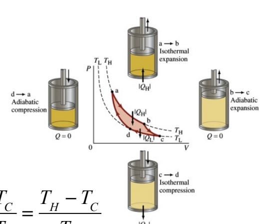
The second law of thermodynamics. The Carnot cycle.

- 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:

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



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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.

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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 August 31.
- 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).

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

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