Physics 2c Lecture 7

Last Lecture:

Efficiency of Heat Engines

This Lecture:

Heat pump and fridge

2nd law of thermodynamics

Real vs idealized engines

Thermodynamic Temperature Scale

Things to Ponder

Efficiency of Carnot Engine

$$\varepsilon = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

$$\varepsilon = 1 - \frac{T_c}{T_h}$$

Quiz on Monday

- The quiz covers everything in the book in chapters 19,20,21
- In addition, it covers everything we covered yesterday out of chapter 22:
  - Heat Engines
  - Fridges and heat pumps

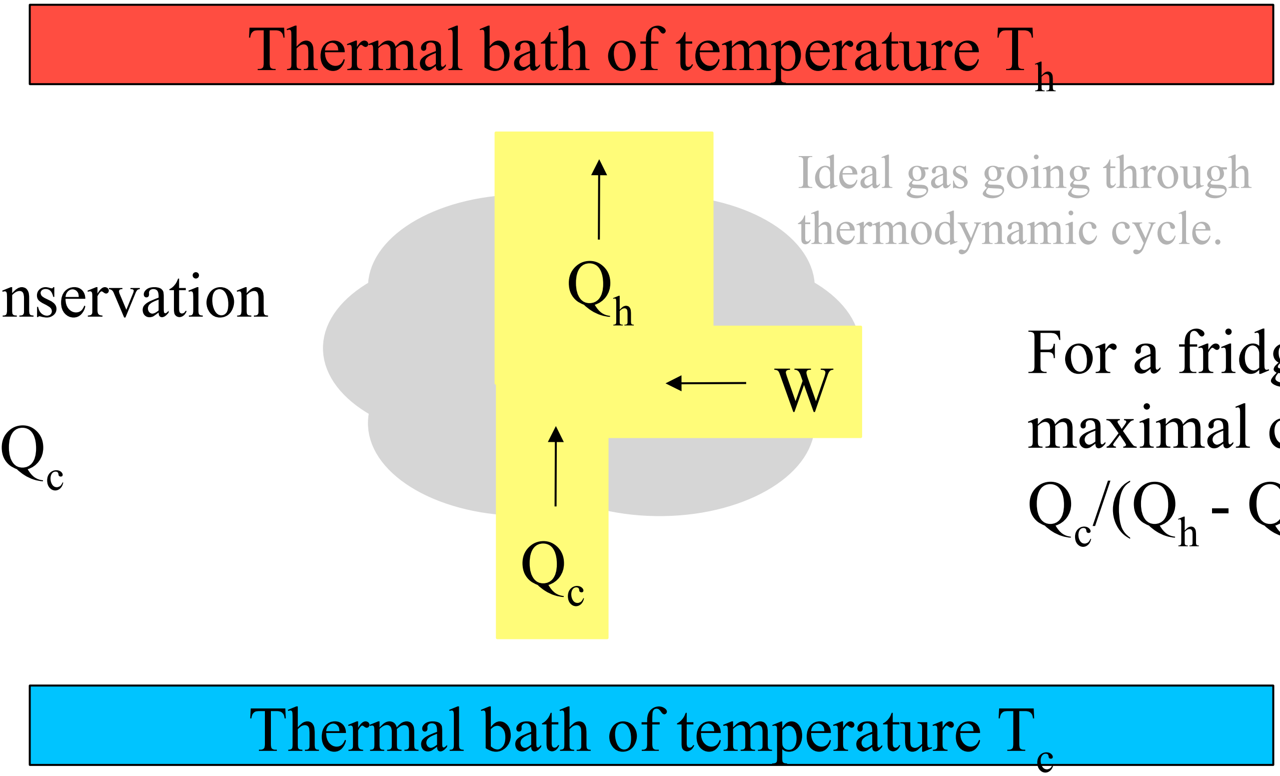
We used Carnot Engine to explicitly show:

$$\frac{Q_c}{Q_h} = \frac{T_c}{T_h}$$

Objective of Fridge/heat pump

- Use work to move heat from a cold place to a hot place.
- Examples:
  - A fridge takes heat from the inside of the fridge and dumps it into the kitchen in order to keep the inside of the fridge cold.
  - A heat pump takes heat from the outside of the house and dumps it into the inside of the house in order to keep the inside of the house warm.

Schematic of a refrigerator (or heat pump)



Thermal bath of temperature T_h

Ideal gas going through thermodynamic cycle.

Thermal bath of temperature T_c

Energy conservation requires:
$W = Q_h - Q_c$

For a fridge, we want maximal coeff. of perf.: $Q_c/(Q_h - Q_c)$

How good a heat pump do you have?

$$COP = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c} = \frac{T_C}{T_h - T_C}$$

Comparing Fridge & Engine

Engine	Fridge
obtain work	expend work
move heat from hot to cold	move heat from cold to hot
max. eff. for max. dT	max. COP for min. dT

Today's topics:

2nd law of thermodynamics

We will look at the second law in 3 different formulations.

2nd Law of Thermo a la Kelvin-Planck

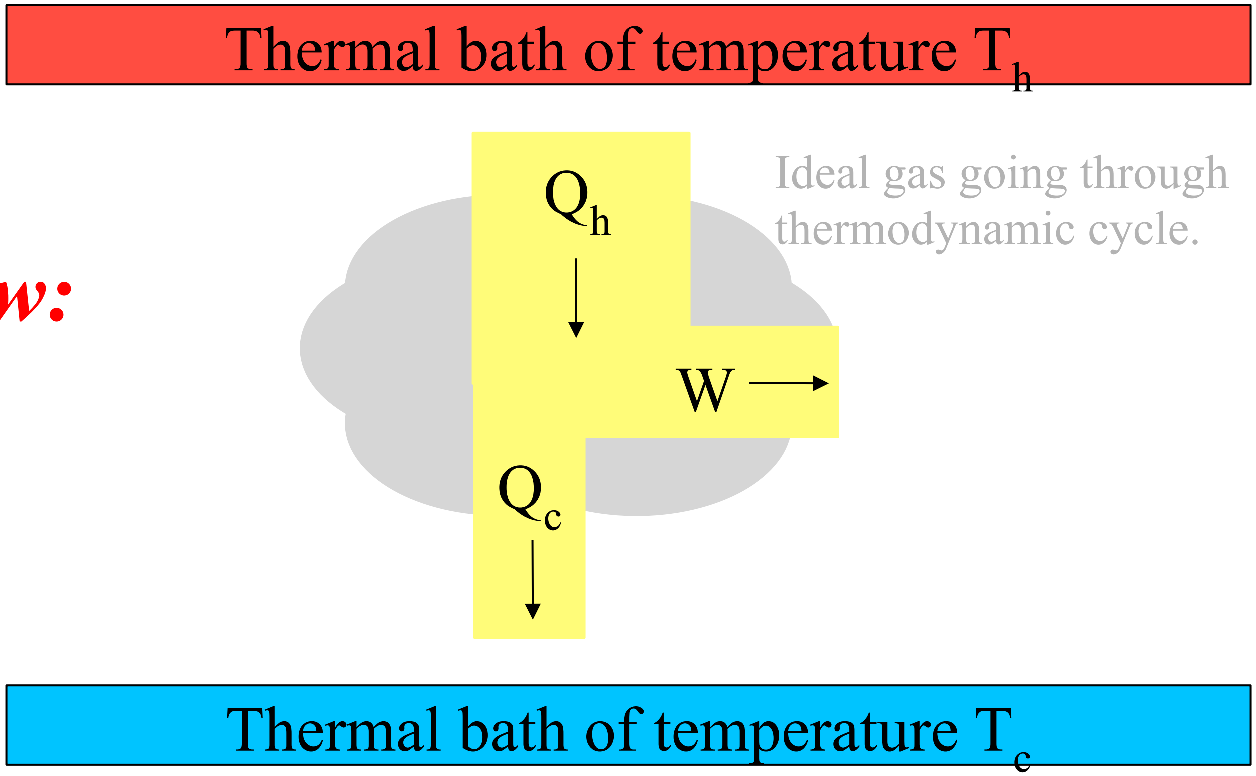
It is impossible to construct a heat engine

operating in a cycle that extracts heat

from a reservoir

and delivers equal amount of work.

Schematic of a heat engine



Thermal bath of temperature T_h

Q_h

Ideal gas going through thermodynamic cycle.

W

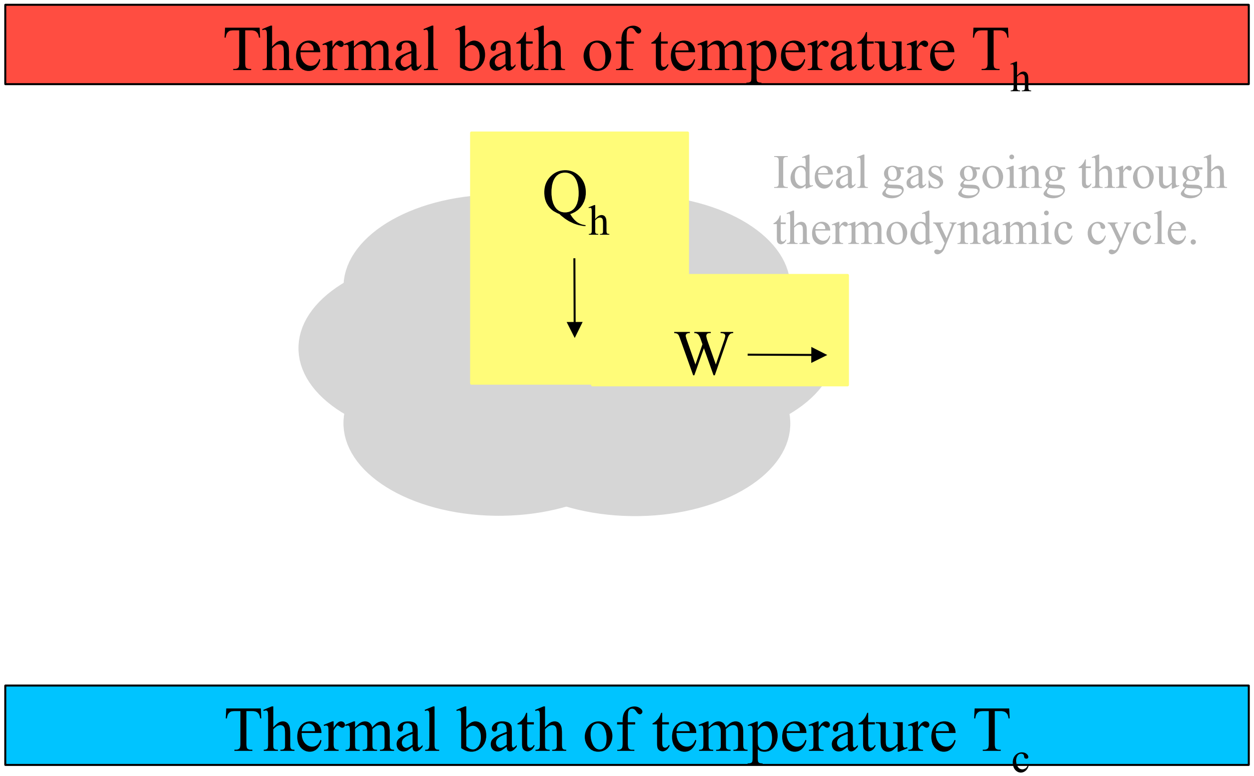
Q_c

Thermal bath of temperature T_c

2nd Law:

$Q_c > 0$

This is not possible!



Thermal bath of temperature T_h

Q_h ↓

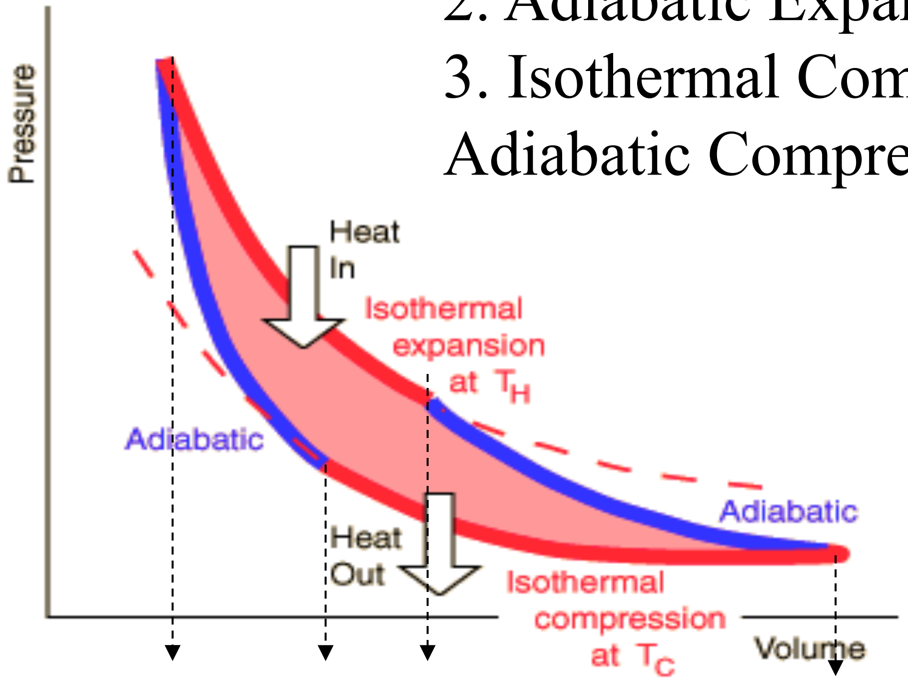
W →

Ideal gas going through thermodynamic cycle.

Thermal bath of temperature T_c

Carnot engine, a 4 step process

1. Isothermal Expansion (V_A -> V_B)
2. Adiabatic Expansion (V_B -> V_C)
3. Isothermal Compression (V_C -> V_D) 4.
Adiabatic Compression (V_D -> V_A)



$$Q = nRT \ln \frac{V_{final}}{V_{initial}}$$

$$Q(V_C \rightarrow V_D) = nRT_c \ln \frac{V_D}{V_C}$$

For a Carnot engine, 2nd law is sort of obvious.

2nd Law of Thermo a la Clausius

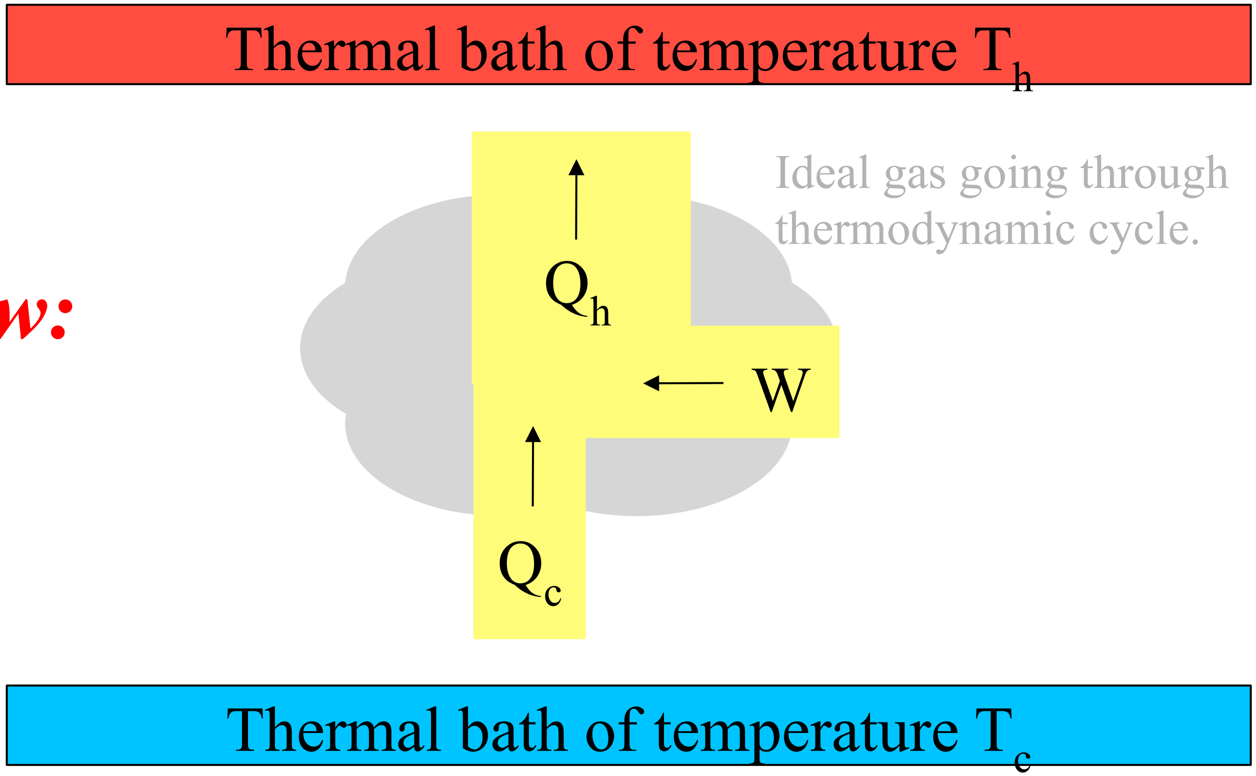
It is impossible to construct a refrigerator

operating in a cycle

whose sole effect is to transfer heat

from a cooler object to a hotter object.

Schematic of a refrigerator



Thermal bath of temperature T_h

Ideal gas going through thermodynamic cycle.

Q_h

W

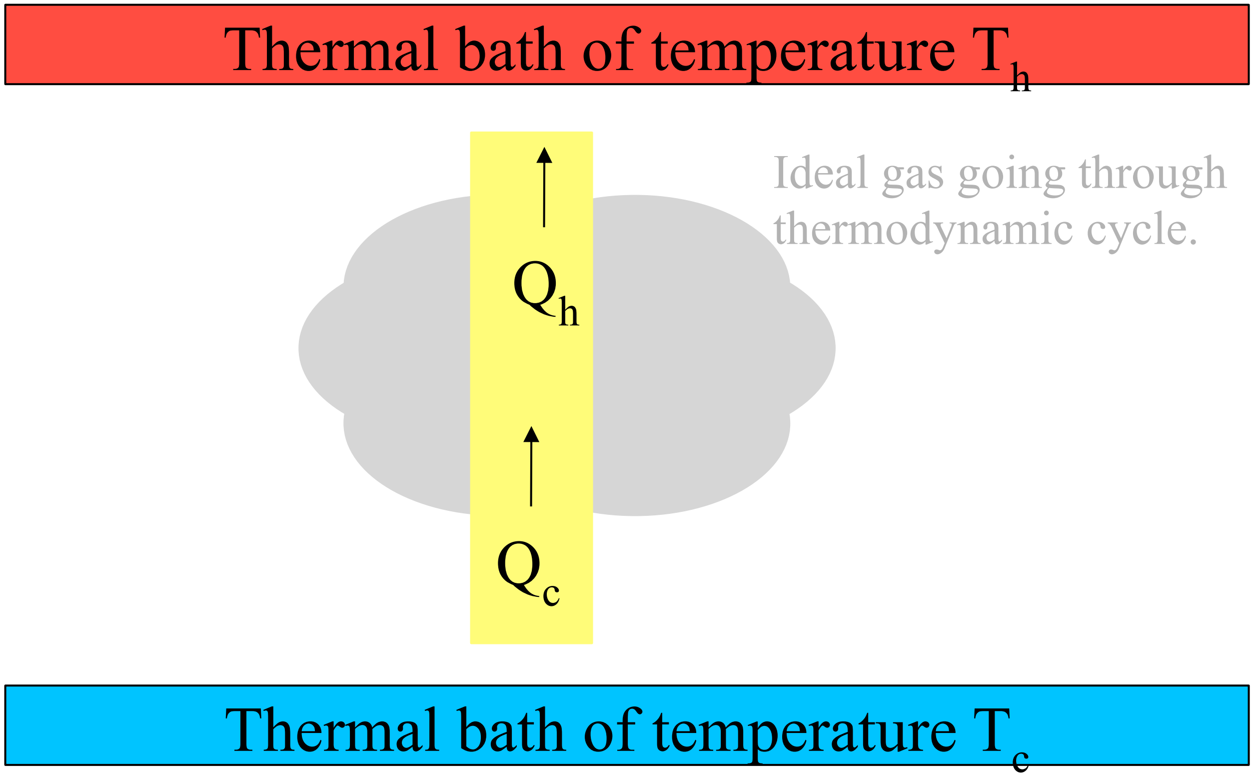
Q_c

Thermal bath of temperature T_c

2nd Law:

$W > 0$

This is not possible!



Thermal bath of temperature T_h

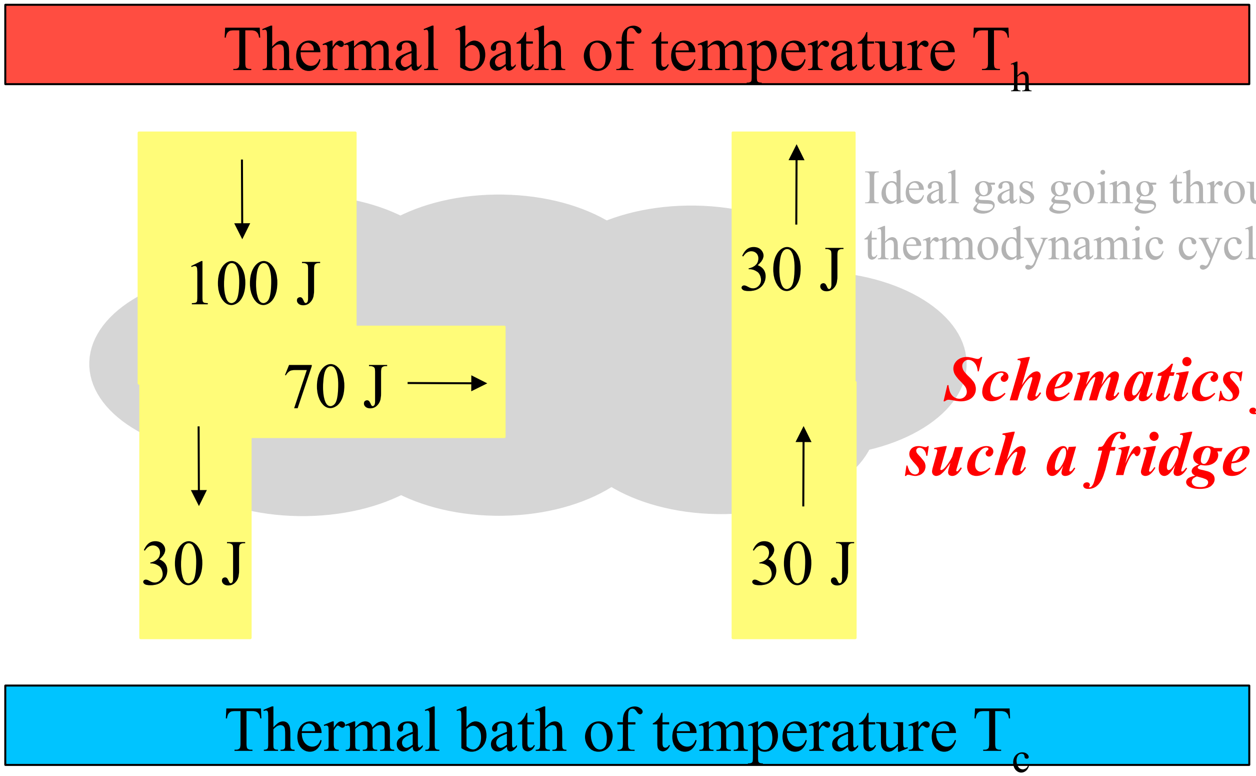
Ideal gas going through thermodynamic cycle.

Q_h

Q_c

Thermal bath of temperature T_c

Combining engine & fridge



Thermal bath of temperature T_h

100 J

70 J →

30 J

30 J

Ideal gas going through thermodynamic cycle.

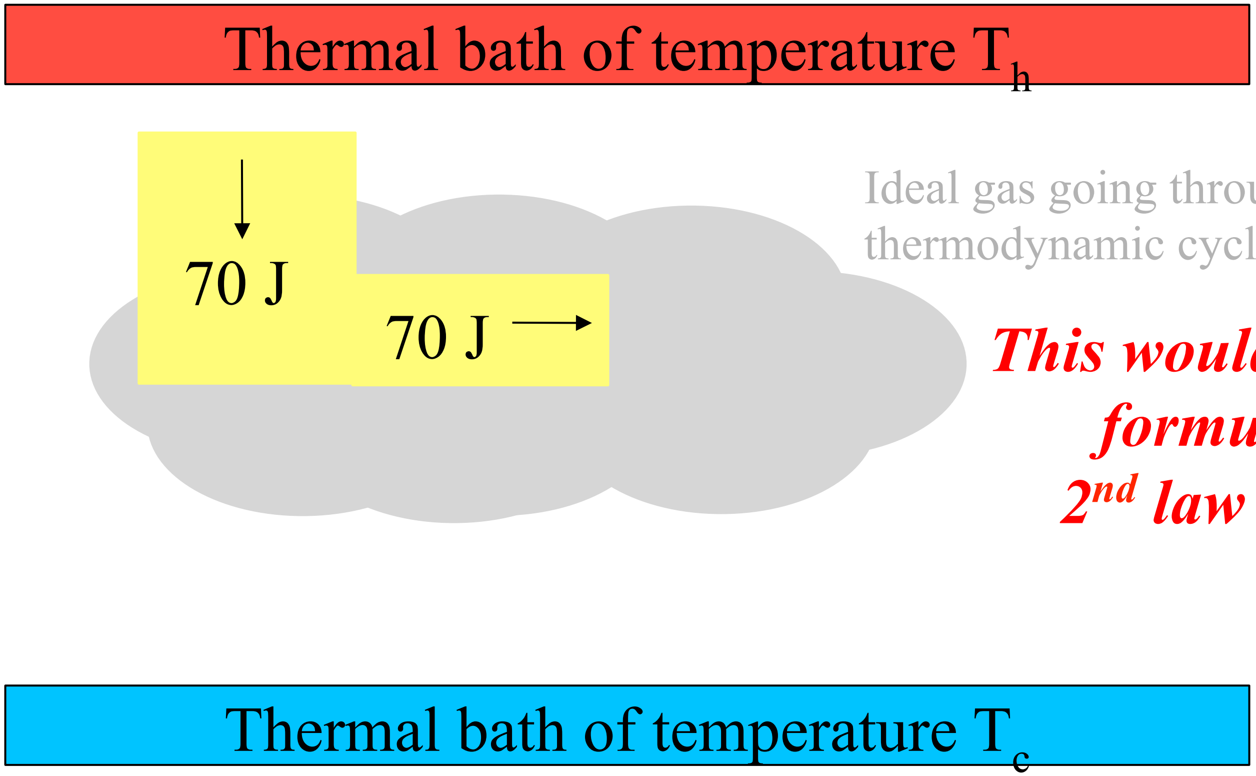
30 J

Thermal bath of temperature T_c

Schematics for combining such a fridge with an engine.

If such a fridge existed then the 2nd law is violated by the combo

Combining engine & fridge



Thermal bath of temperature T_h

70 J

70 J

Ideal gas going through thermodynamic cycle.

This would violate K-P formulation of
2^{nd} law of thermo

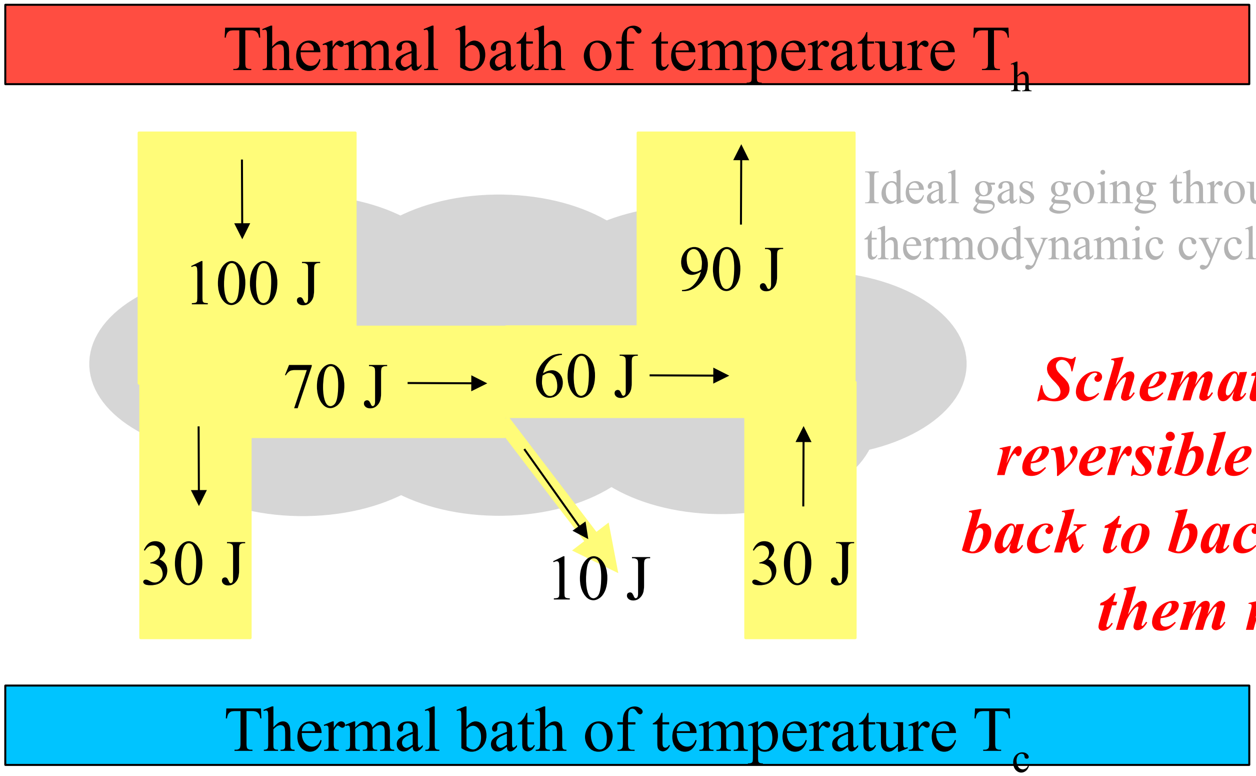
Thermal bath of temperature T_c

2nd Law of Thermo a la Carnot

All reversible Carnot engines operating between temperatures T_c, T_h have the same efficiencies.

No other engine operating between the same temperatures can have a larger efficiency.

Combining engine & fridge

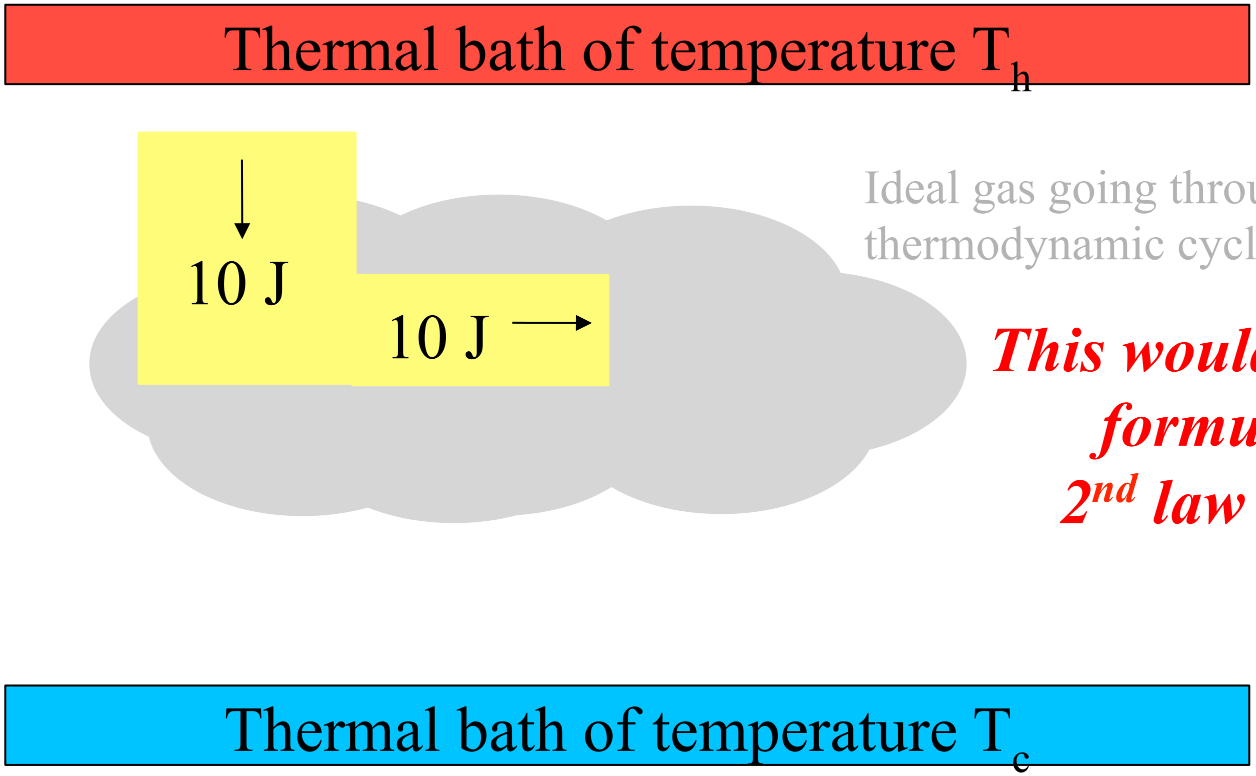


Ideal gas going through thermodynamic cycle.

Schematics for two reversible engines run back to back, with one of them reversed.

If they don't have the same efficiency then net work is left.

Combining engine & fridge



Thermal bath of temperature T_h

10 J

10 J

Ideal gas going through thermodynamic cycle.

This would violate K-P formulation of 2nd law of thermo

Thermal bath of temperature T_c

But ...

We all know, not all engines are equally efficient!

What's wrong here ?

Ideal vs Real engines

Ideal	Real
reversible process	irreversible process
no losses due to friction etc.	friction and other losses
maximal efficiency possible	less than maximal efficiency

A real (lower efficiency) engine can not be reversed into a fridge at the same operating points.

Thermodynamic Temperature Scale

1. Pick a reference point T_{ref}
   e.g. convenient triple point or well def. phase transition.
2. Measure the efficiency of Carnot process
   between unknown T and T_{ref} .
3. Calculate T from $e_{Carnot} = 1 - T/T_{ref}$

This is used in low temperature research when there is no other convenient thermometer available.

Things to ponder ...

Are all types of energy created equal?

What's the nature of absolute zero T?

What role plays order and disorder?

Quality of Energy: Mixing of water

Take 1kg of boiling water, and toss it into
1kg of water at 0 degree Celsius.
You get 2kg of water at 50 degrees Celsius.

You got the same energy but the initial system of two baths could have been used to do work. Whereas a system of two baths at the same temperature can NOT be used as a heat engine.

Clearly, not all energy is created equal !!!

Not all energy is created equal

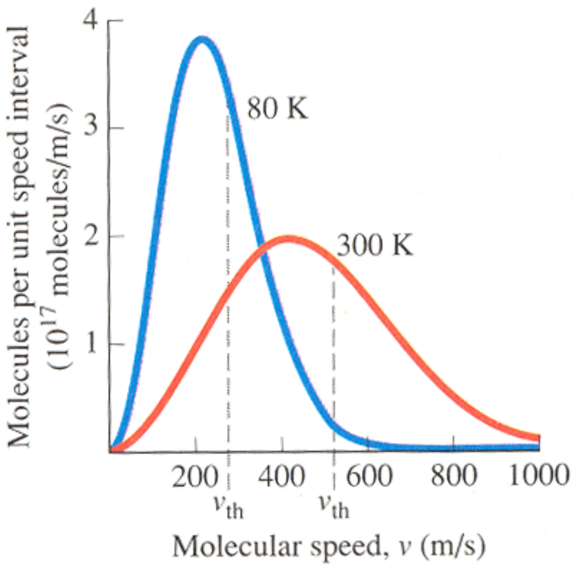
- If you give me energy, I want it in a form such that it is useful for doing work.
  - This means I want it in form of a hot and cold bath, with *maximum* ΔT between the two.
- Let’s look at our model of an ideal gas to see what this means.

Ideal Gas Recap

- $< E_{kin} > = 1/2\ m < v^2 > = 3/2\ kT$
- Observation: T is positive definite !!!
- Distribution of velocities:

Ideally, I'd like my Gas nicely ordered, in buckets with a small v^2 range.

Unfortunately, this is fundamentally not possible.



Maxwell’s daemon

- If this strikes your fancy, consider reading up on it in Wikipedia:
- http://en.wikipedia.org/wiki/Maxwell's_demon
- It’s philosophically fascinating, but in the end, the second law of thermo wins.