Lecture 10

April 23, 2012

Chapter III of RK

Heat Engines and thermodynamics

1st Law of Thermodynamics:
Heat and Work are on the same footing

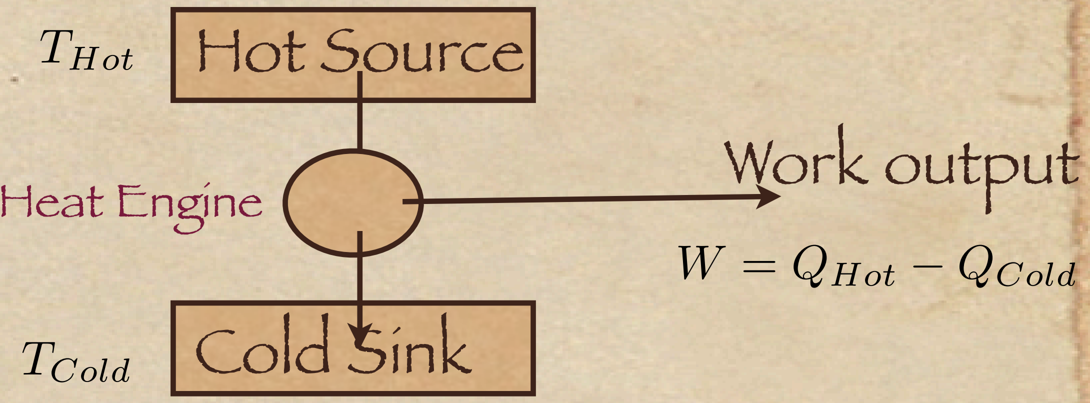
$$\Delta U = \Delta Q + \Delta W$$

We can convert work done to heat with great effectiveness: Think heated wire (Joule heating of resistors)

BUT: The converse is not so easy!

Converting heat into useful work is only possible in a "Lossy" fashion- we lose some heat to unwanted waste.

$$\text{Efficiency} = \frac{\text{Work done}}{\text{energy put into system}} \times 100\%$$



$$\text{Efficiency} = \frac{Q_{Hot} - Q_{Cold}}{Q_{Hot}} \times 100\%$$

$$\text{Efficiency(Carnot)} = \frac{T_{Hot} - T_{Cold}}{T_{Hot}} \times 100\%$$

Carnot showed that this is optimal.
(Cannot beat Carnot)

Summary: Carnot showed: Q(Cold) /Q(Hot) is at most T(Cold)/T(Hot)

In general Q is a complex object but T is simple (just measure it!). Hence this is a great simplification.

Examples:

Carnot's Car: T(Hot)= Burning temp of fuel, T(Cold)= atmospheric temp (1000-20)/1000 x 100 = 98%

Real cars ~25 to 30%

Coal fueled Power plant: T(Hot) = Coal temp, T(Cold)= river temperature;

Questions:
Why do we lose so much, is this preventable?
What, if anything, went wrong with 1st law of thermodynamics?
Is there a piece of the story that we haven't learnt yet?

Converting mechanical energy to
heat energy is easy, converse is difficult,
although allowed by 1st Law of thermodynamics

Efficiency definition and Carnot cycles emerge next.

2nd Law of thermodynamics

- It is impossible for a machine to take heat from a reservoir at T, produce work and exhaust heat into a reservoir at same T .
- Systems isolated from the environment will move towards equilibrium with their surroundings.

Linked ideas/concepts
Impossibility of perpetual motion.

Arrow of time:

Example: glass of water with ice in it will warm up in a room at normal temperatures: (e.g. 65°F) .
A Gas on one side of a chamber will fill both sides on removing partitions.

Other consequences:

* 1. Heat will not flow spontaneously from a cold object to a hot object.

* 2. Any system which is free of external influences becomes more disordered with time. This disorder can be expressed in terms of the quantity called entropy.

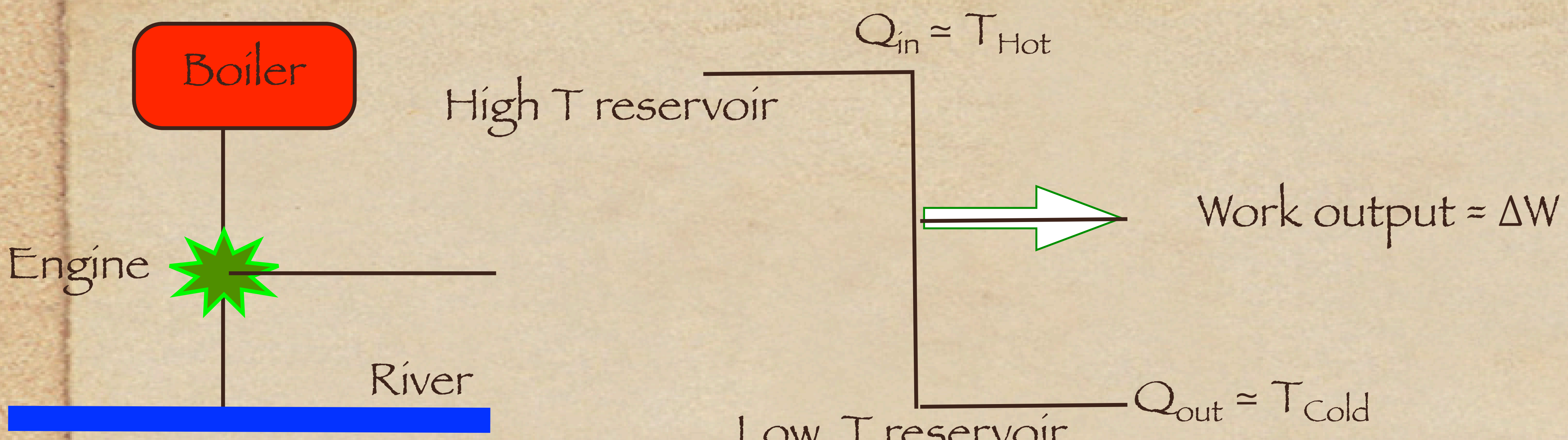
* 3. You cannot create a heat engine which extracts heat and converts it all to useful work.

* 4. There is a thermal bottleneck which constrains devices which convert stored energy to heat and then use the heat to accomplish work. For a given mechanical efficiency of the devices, a machine which includes the conversion to heat as one of the steps will be inherently less efficient than one which is purely mechanical.

COMMENTS

First law does not preclude this!

Entropy makes its grand entrance here. It is a measure of how disordered the system is. At T=0 Kelvin, entropy is zero since all motion ceases (Barring QM zero point motion)



First Law implies that

$$Q_{in} - Q_{out} \approx \Delta W$$

Second Law says:
There is an intrinsic limit
on how good our engine can get

$$\eta(Carnot) = \frac{T_{Hot} - T_{Cold}}{T_{Hot}} \times 100\%$$

$$\eta \leq 100\%$$

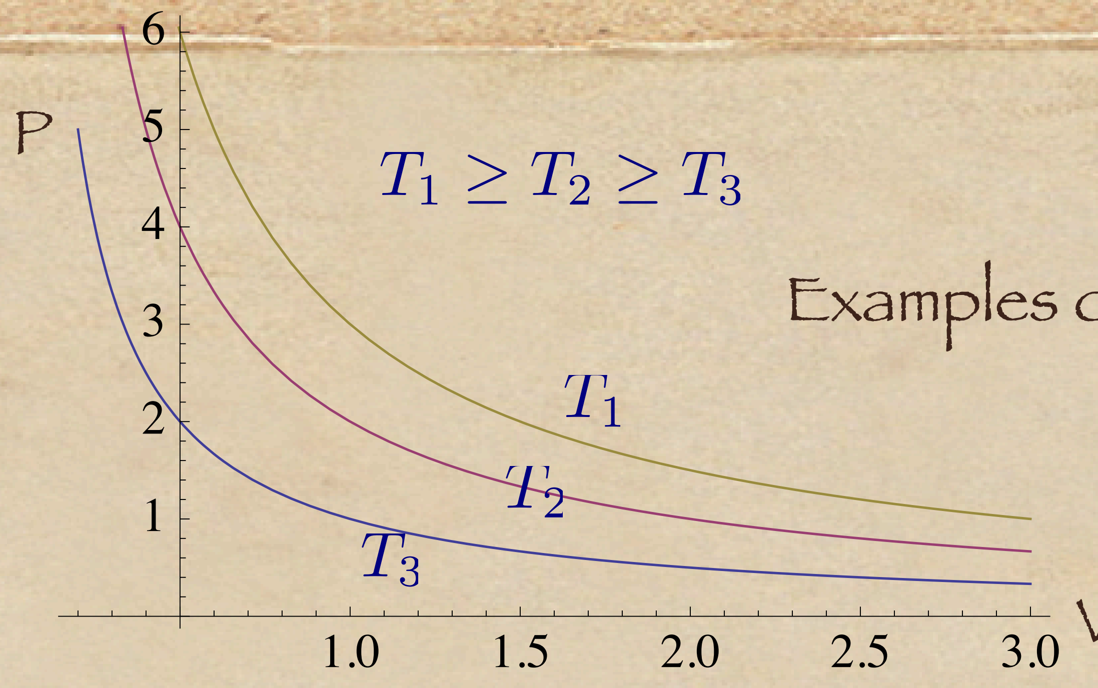
Carnot efficiency:

Key ideas to note:

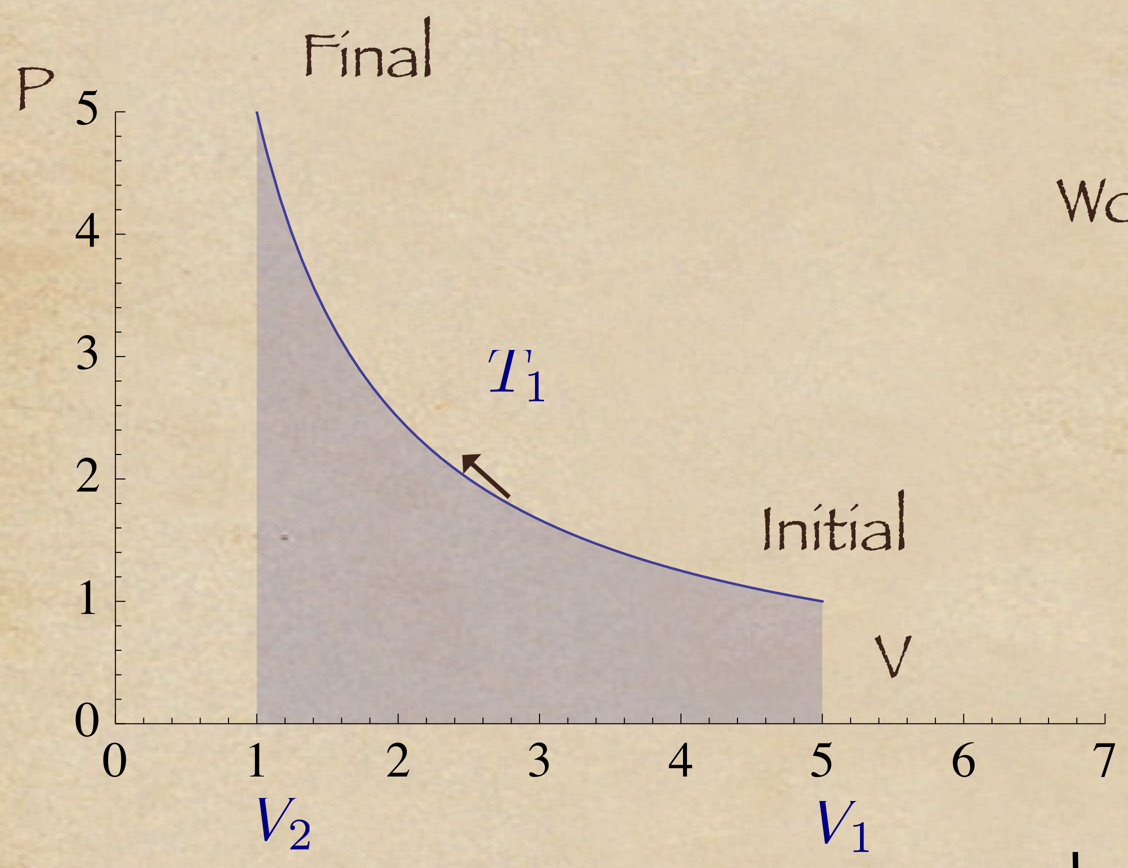
- p V curves: ideal gases and fluids
- Work done as area of p V curve
- reversible processes versus irreversible processes
- isothermal processes
- adiabatic processes
- Cyclic process and work done in such a process
- Carnot's cycle and ideal engine
- Heat Pumps

Ideal gas laws:

$$PV = nk_BT$$



Examples of Isotherms



Work done is equal to area under curve:

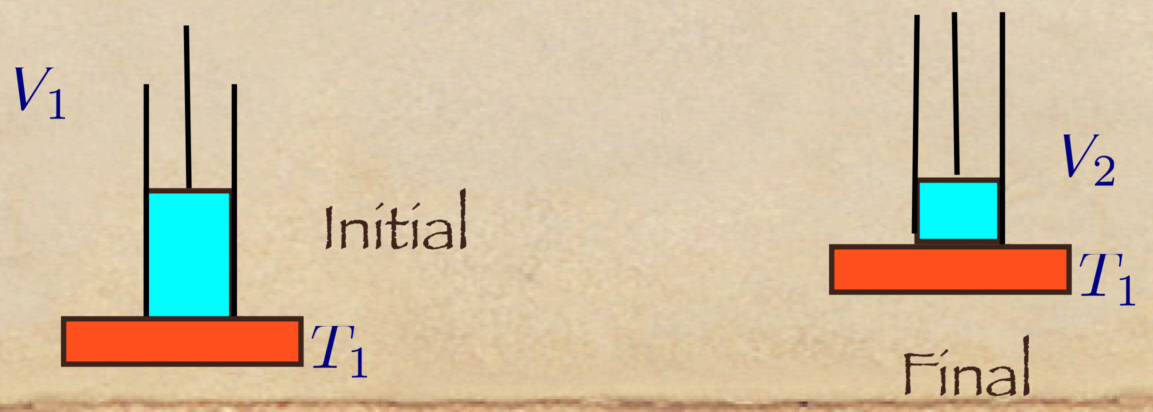
$$[P] = \text{Force}/\text{Area}$$

$$[\Delta V] = \text{Area Length}$$

$$[P\ \Delta V] = \text{Force Length} = \text{Energy}$$

$$\Delta V = \text{Volume change}$$

$$-P\Delta V = \text{Work done on fluid}$$



Irreversible versus reversible changes

Reversible and Irreversible processes:

Mechanical processes:	Thermodynamic processes:
Reversible processes examples • Projectile with no air resistance (e.g. on moon) • Particle slides without friction on a very smooth table top, e.g. hockey puck on ice. • Newton's laws: e.g. planetary motion • Schrodinger equation in QM.	**Reversible processes examples** • Slow compression so that at any point one is very close to equilibrium. • Slow expansion of a fluid
Irreversible processes examples Adding friction and viscosity make things irreversible: Effect of friction is to convert mechanical energy to heat energy. e.g. heating of a particle due to friction.	**Irreversible processes examples** • Spontaneous transfer of heat from hot body to cold body: e.g. all the mixing problems • Ice melting to give water at same temperature