DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

TSOKOS OPTION B-2B THERMODYNAMICS (B2.6 THRU B2.9)

Essential Idea:

- The first law of thermodynamics relates the change in internal energy of a system to the energy transferred and the work done. The entropy of the universe tends to a maximum.

Nature Of Science:

- Variety of perspectives: With three alternative and equivalent statements of the second law of thermodynamics, this area of physics demonstrates the collaboration and testing involved in confirming abstract notions such as this.

International-Mindedness:

- The development of this topic was the subject of intense debate between scientists of many countries in the 19th century.

Understandings:

- The first law of thermodynamics
- The second law of thermodynamics
- Entropy
- Cyclic processes and pV diagrams
- Isovolumetric, isobaric, isothermal and adiabatic processes
- Carnot cycle
- Thermal efficiency

Applications And Skills:

- Describing the first law of thermodynamics as a statement of conservation of energy
- Explaining sign convention used when stating the first law of thermodynamics as $Q = \Delta U + W$
- Solving problems involving the first law of thermodynamics

$pV^{5/3} = \text{constant}$

Applications And Skills:

- Describing the second law of thermodynamics in Clausius form, Kelvin form and as a consequence of entropy
- Describing examples of processes in terms of entropy change
- Solving problems involving entropy changes

$pV^{5/3}$ = constant

Applications And Skills:

- Sketching and interpreting cyclic processes
- Solving problems for adiabatic processes for monatomic gases using $pV^{5/3}$ = constant
- Solving problems involving thermal efficiency

Guidance:

- If cycles other than the Carnot cycle are used quantitatively, full details will be provided
- Only graphical analysis will be required for determination of work done on a pV diagram when pressure is not constant

Data Booklet Reference:

$$Q = \Delta U + W$$

$$U = \frac{3}{2} nRT$$

$$\Delta S = \frac{\Delta Q}{T}$$

$$pV^{\frac{5}{3}} = constant$$ *(for monatomic gases)*

$$W = p\Delta V$$

$$\eta = \frac{useful work done}{energy input}$$

$$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$$

Utilization:

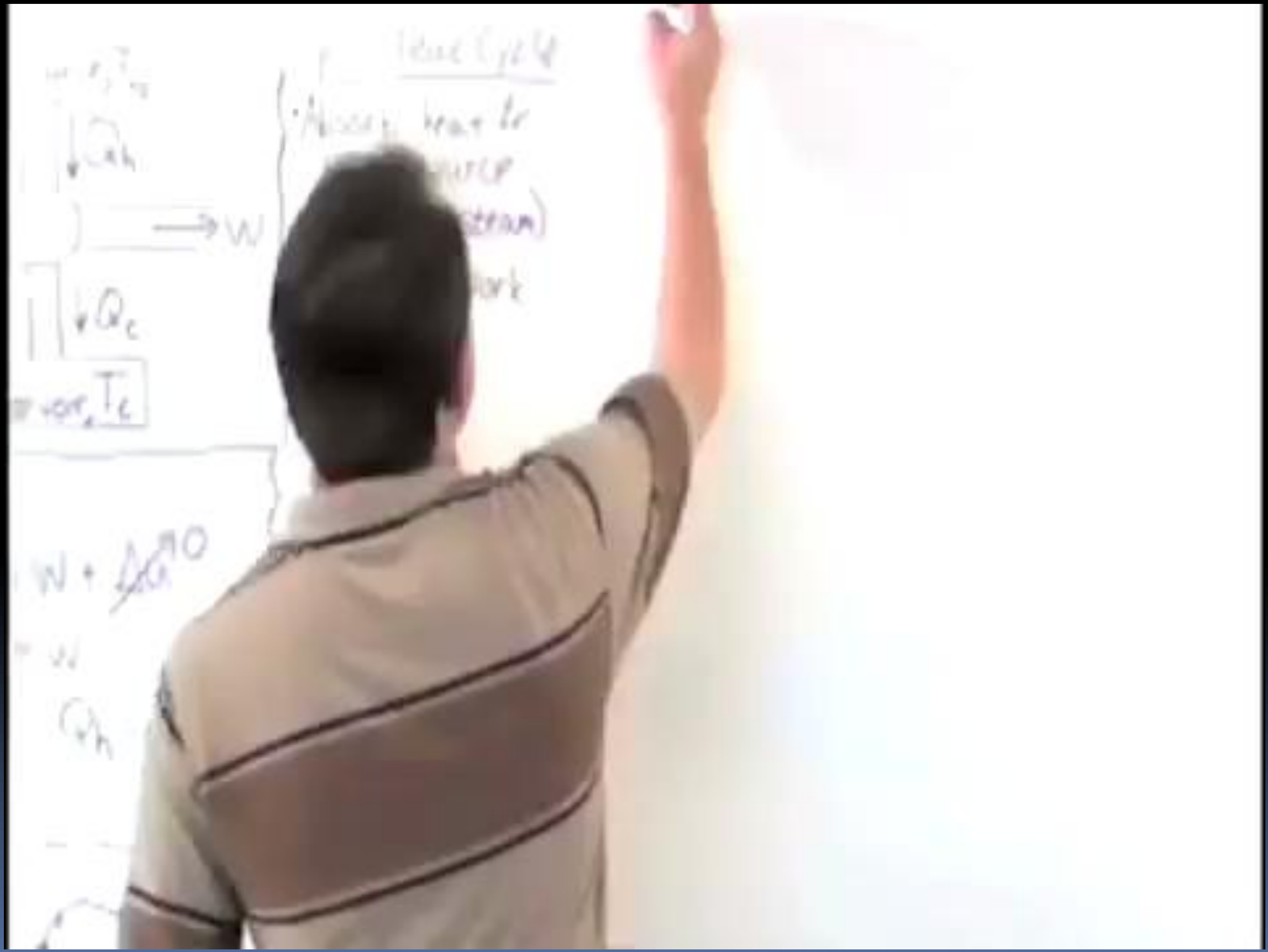
- This work leads directly to the concept of the heat engines that play such a large role in modern society
- The possibility of the heat death of the universe is based on ever-increasing entropy
- Chemistry of entropy (see Chemistry sub-topic 15.2)

Aims:

- Aim 5: development of the second law demonstrates the collaboration involved in scientific pursuits
- Aim 10: the relationships and similarities between scientific disciplines are particularly apparent here

Reading Activity Questions?

Introductory Video: Efficiency and the Second Law of Thermodynamics

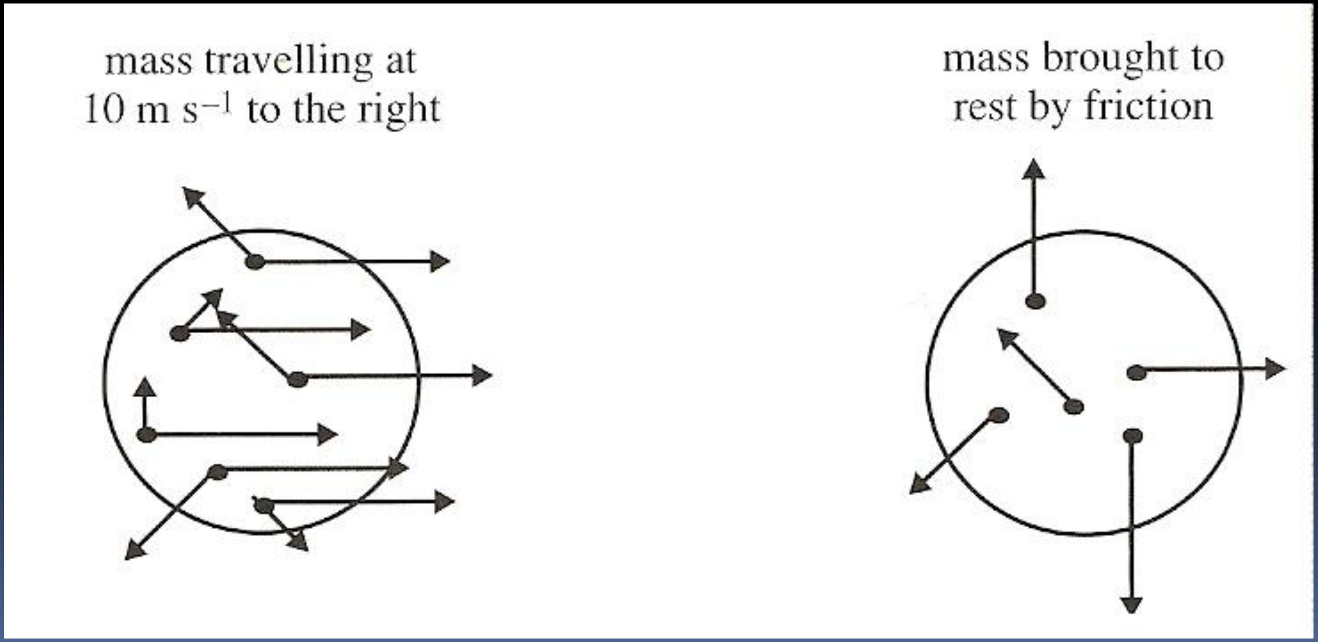


Second Law of Thermodynamics

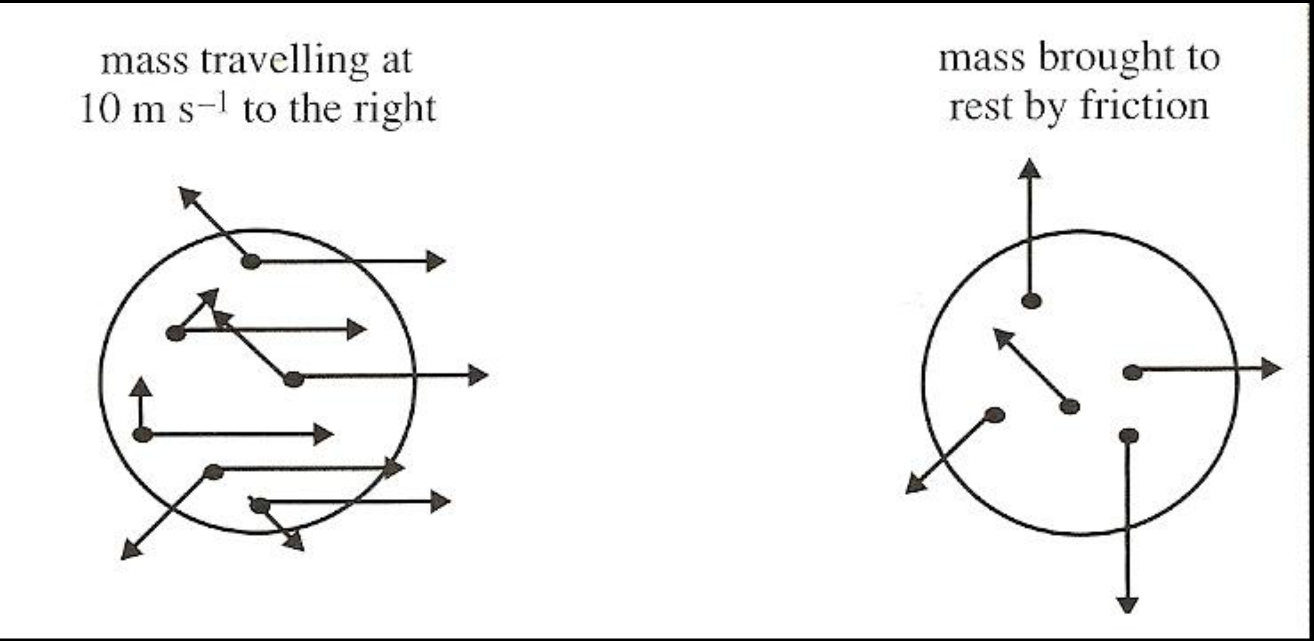
- Impossible processes consistent with the First Law
  - The spontaneous (i.e. without the action of another agent) transfer of thermal energy from a cold body to a hotter body
  - The air in a room suddenly occupying just one half of the room and leaving the other half empty
  - A glass of water at room temperature suddenly freezing, causing the temperature of the room to rise

Second Law of Thermodynamics

- Order and Disorder – Consider a bowling ball rolled down the hall in between classes
  - Between collision with students and friction, the ball eventually comes to a stop.



Second Law of Thermodynamics



- Once the ball comes to a stop, the ordered kinetic energy can't be recovered because it has been degraded.
- All that is left is the disordered heat energy caused by friction

Second Law of Thermodynamics

- The Second Law of Thermodynamics deals with the limitations imposed on heat engines, devices whose aim is to convert thermal energy (disordered energy) into mechanical energy (ordered energy).

Second Law of Thermodynamics

- Reversibility
  - All natural processes are irreversible
  - They lead to a state of increased disorder
- Measure of Disorder – ***Entropy***
  - State function – once the state of the function is specified, so is the entropy

Entropy

$$\Delta S = \frac{Q}{T}$$

- During an isothermal expansion of a gas, the gas must receive heat
- During an isothermal compression of a gas, the gas expels heat
- The net change in entropy is zero

$$\Delta S_E = \frac{Q}{T}$$

$$\Delta S_E \rangle 0$$

$$\Delta S_C = \frac{-Q}{T}$$

$$\Delta S_C \langle 0$$

Entropy

- The entropy of heat flowing from a hot object to a cold one
- The hot object loses heat, the cold one gains heat
- Entropy increases

$$\Delta S = \frac{Q}{T}$$

$$\Delta S = \frac{-Q}{T_H} + \frac{Q}{T_C}$$

$$\Delta S = Q\left(\frac{1}{T_C} - \frac{1}{T_H}\right)$$

$$\Delta S_E \rangle 0$$

Entropy

$$\Delta S = \frac{Q}{T}$$

- The entropy of heat flowing ***to*** a hot object ***from*** a cold one
- The hot object ***gains*** heat, the cold one ***loses*** heat
- Entropy ***decreases***

Ain't Gonna Happen!

$$\Delta S = \frac{Q}{T_H} + \frac{-Q}{T_C}$$

$$\Delta S = Q\left(\frac{1}{T_H} - \frac{1}{T_C}\right)$$

$$\delta S_E \langle 0$$

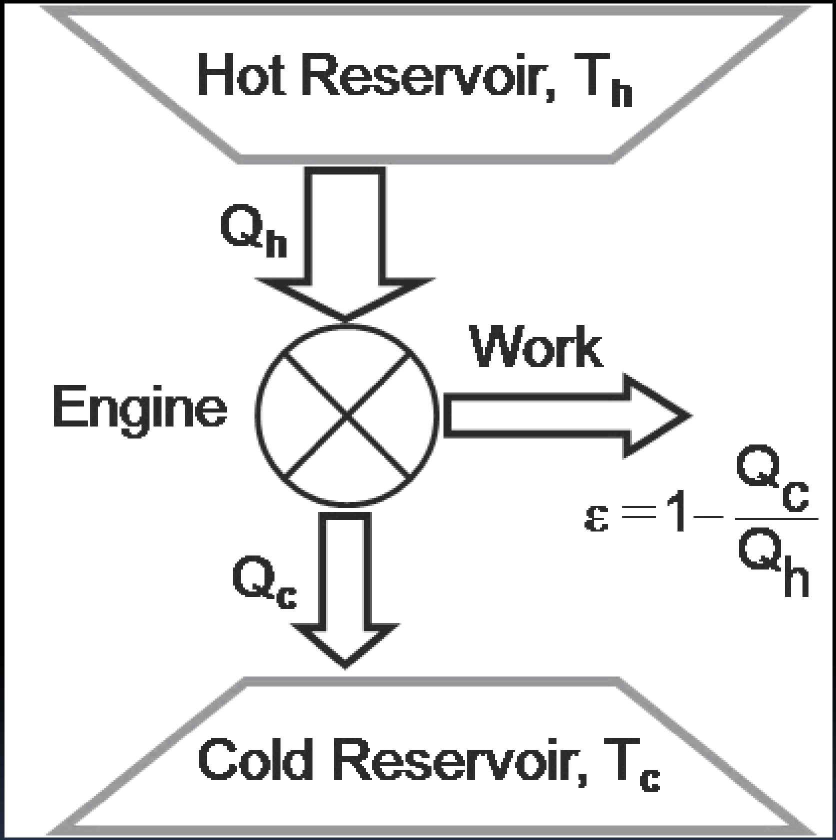
Second Law of Thermodynamics (finally!)

- General Statement:
  - The entropy of an isolated system never decreases. In such a system, entropy increases in realistic irreversible processes and stays the same in theoretical, idealized reversible processes.
- Other Statements:
  - It is impossible for thermal energy to flow from a cold to a hot object without performing work.
  - It is impossible, in a cyclic process, to completely convert heat into mechanical work.

Video: Cyclic Heat Engines

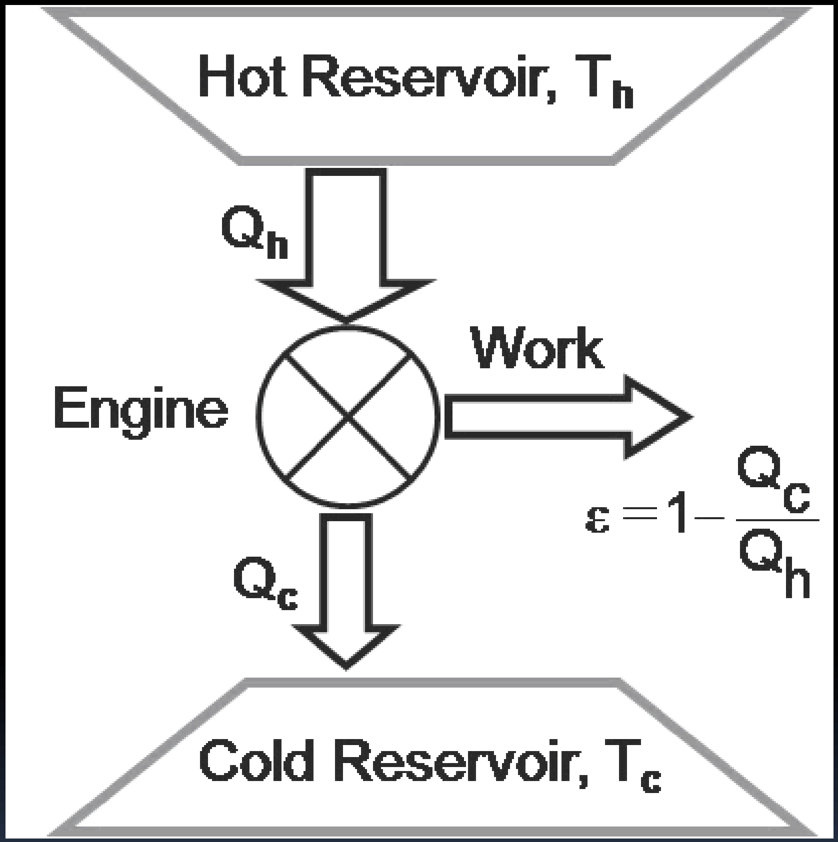
Heat Engines

- A device that converts thermal energy into work
  - A hot reservoir at temperature T_H transfers heat into the engine
  - Think of the engine as a cylinder of gas with a movable piston
  - The expanding gas pushes the piston which does mechanical work



Heat Engines

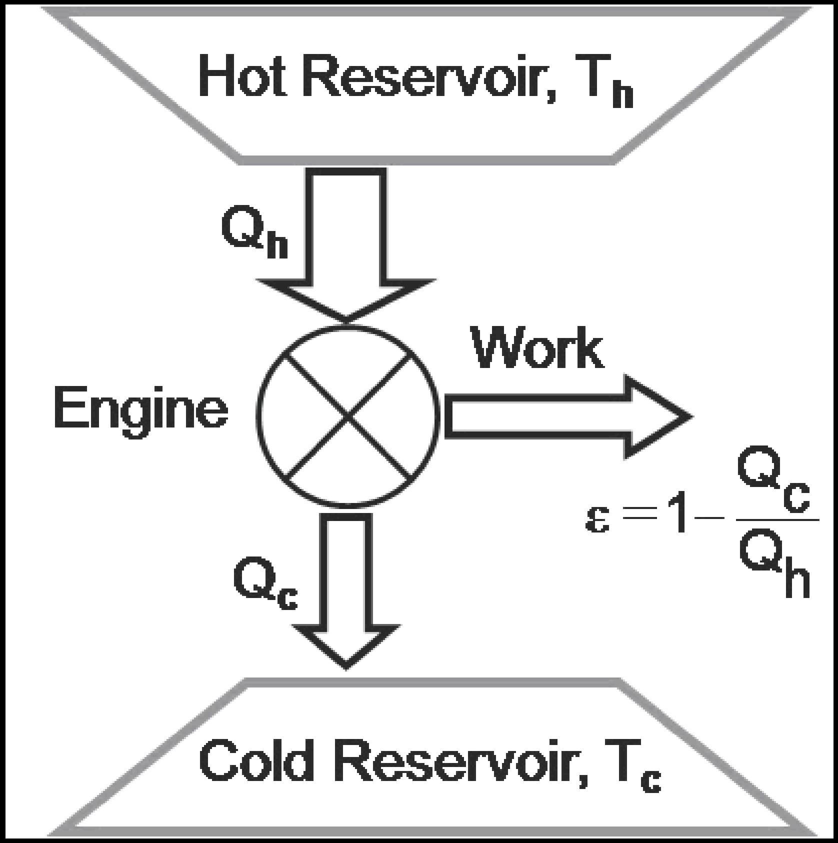
- A device that converts thermal energy into work
  - Not all of the heat can be turned into mechanical work
  - Some is ejected into a sink, or cold reservoir, at temperature T_C

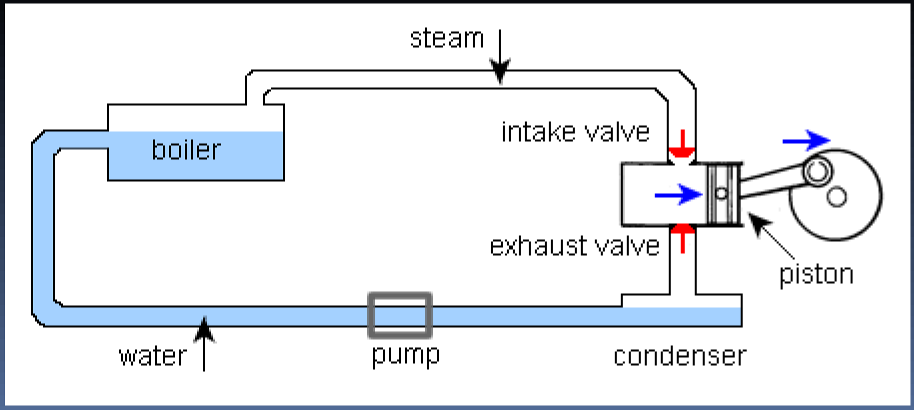


Heat Engines

- A device that converts thermal energy into work
  - If we assume the temperature (internal energy) remains constant, the work done is equal to heat in Q_H minus heat out Q_C

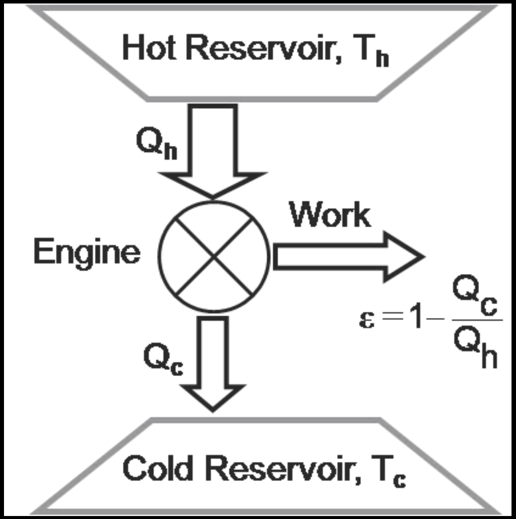
$$Q = \Delta U + W$$

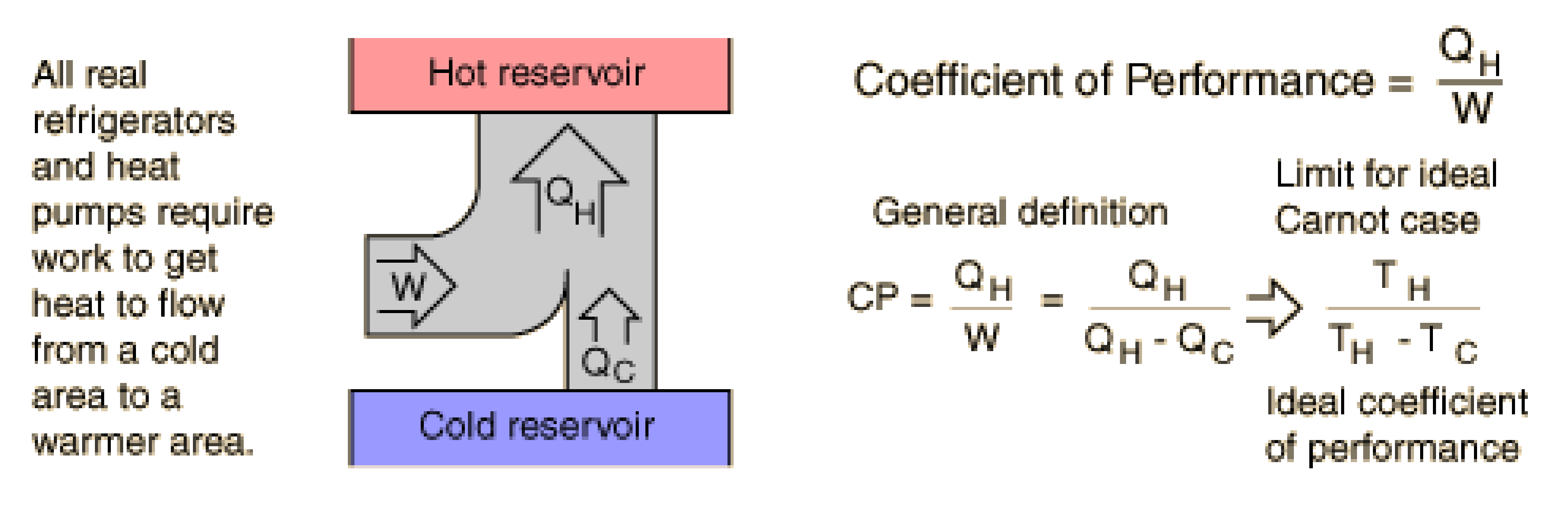




Heat Engines

- A device that converts thermal energy into work
  - Refrigerators and heat pumps use mechanical work to remove heat





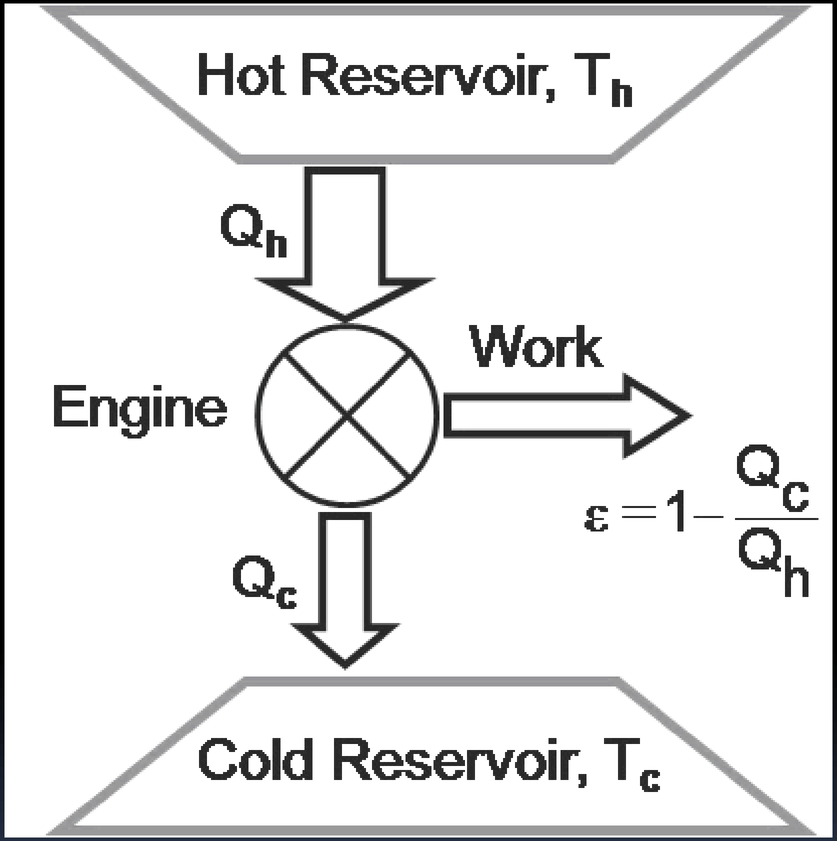
Heat Engines

- Not all of the heat can be turned into mechanical work

$$\eta = \frac{usefulwork}{inputenergy}$$

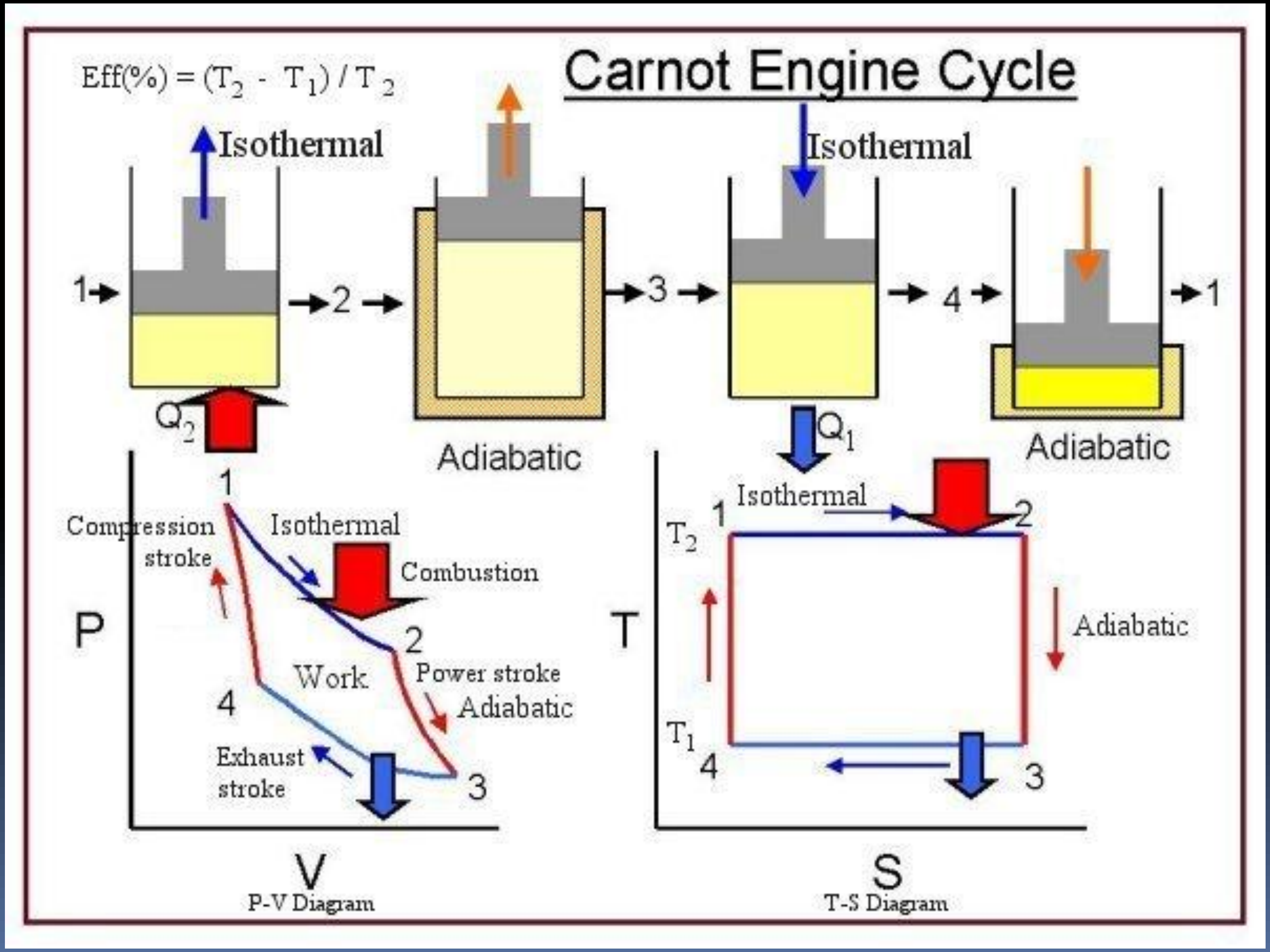
$$\eta = \frac{Q_H - Q_C}{Q_H}$$

$$\eta = 1 - \frac{Q_C}{Q_H}$$



Carnot Engine

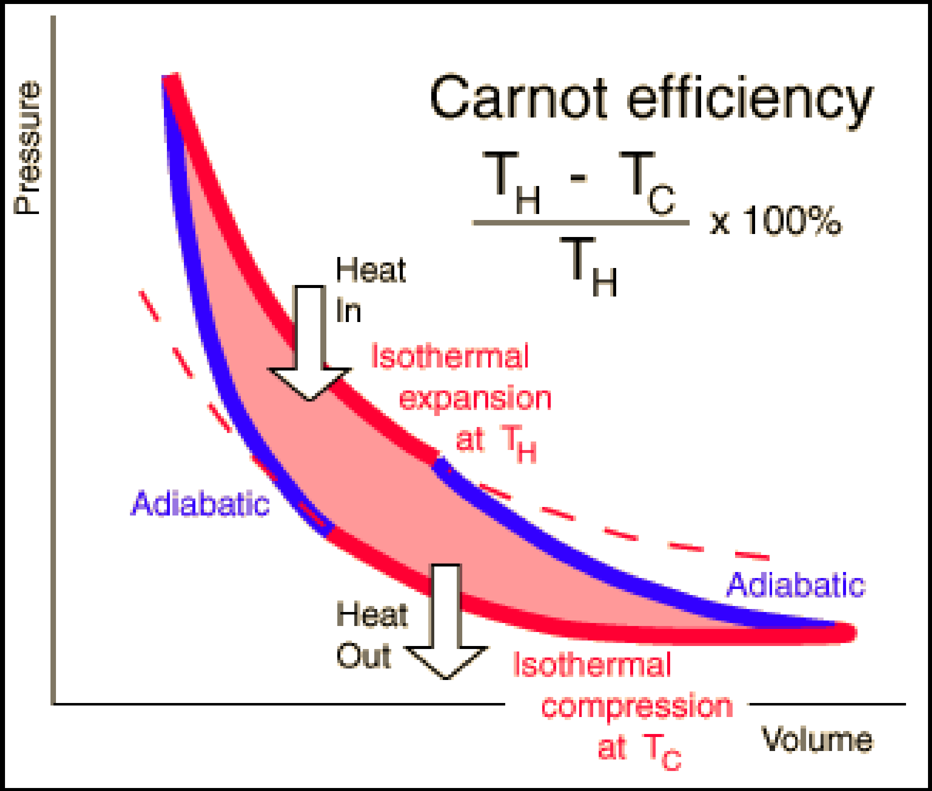
- No engine is more efficient than a Carnot engine operating between the same temperatures.



Carnot Engine

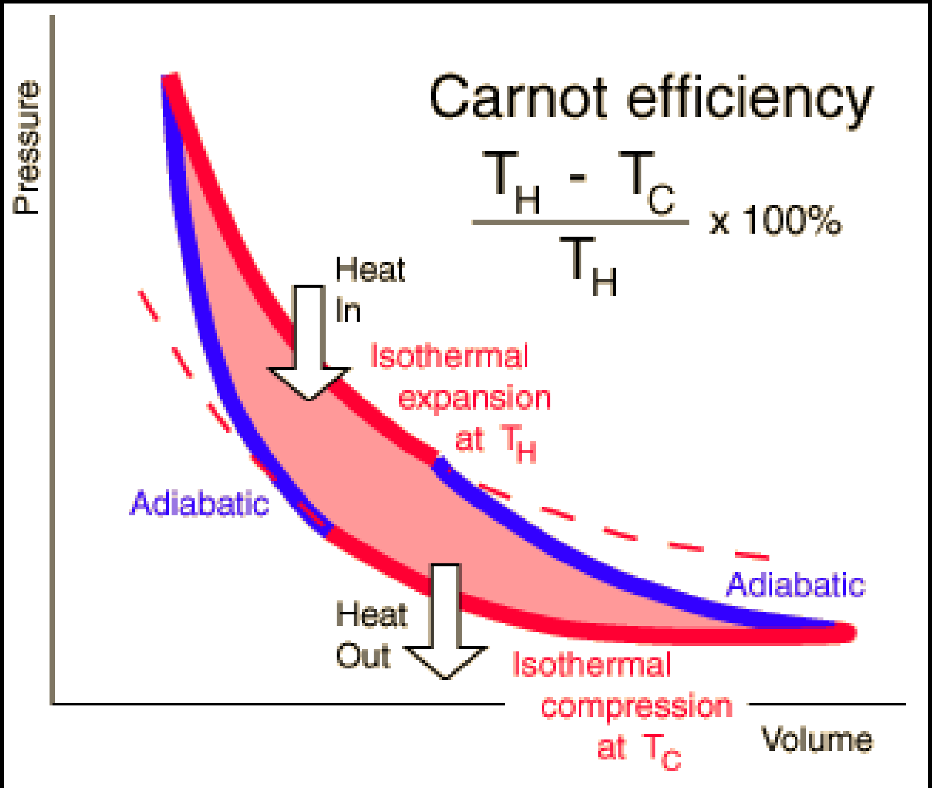
Carnot Engine

- Starts with an isothermal compression (work done on the gas and heat is extracted, Q_C)
- Next the gas is further compressed adiabatically (work done on the gas and increase in temperature)



Carnot Engine

- Gas then expands isothermally (work done by the gas, heat Q_H is drawn in from the hot reservoir)
- Lastly, the gas continues to expand but now adiabatically (work done by the gas, decrease in temperature)



Carnot Engine

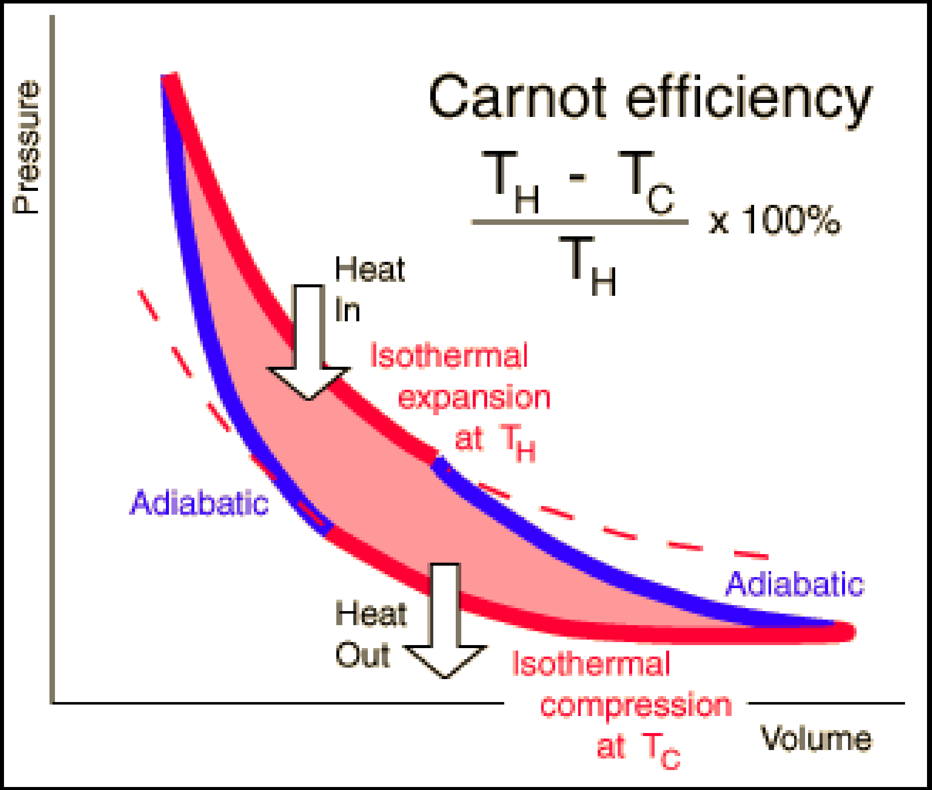
- Since heat is exchanged during isothermal processes,

$$\frac{Q_H}{T_H} = \frac{Q_C}{T_C}$$

$$\frac{T_C}{T_H} = \frac{Q_C}{Q_H}$$

- And efficiency becomes

$$\eta_C = 1 - \frac{T_C}{T_H}$$



Energy Degradation

- The flow of energy from a hotter to a colder object tends to equalize the two temperatures and deprives us of the opportunity to do work.

$$\Delta U = Q - W$$

Energy Degradation

- It is a consequence of the second law that energy, while always being conserved, becomes less useful – this is *energy degradation*.

Energy Degradation of the Universe

- Consider the universe to be a big bag of gas
- As far as we know, the universe is a closed system – no heat is entering the universe
- Since the universe is expanding, positive work is being done

$$\Delta U = 0 - W$$

$$\Delta U \langle 0$$

Energy Degradation of the Universe

- Thus the internal energy of the universe, i.e. its temperature, is constantly decreasing
- This aligns with the idea that the temperature during the BIG BANG was millions of degrees and today, wavelength measurements of electromagnetic radiation left over from the BIG BANG show the temperature

of the universe to be about

2.7K

$$\Delta U = 0 - W$$

$$\Delta U \langle 0$$

Energy Degradation of the Universe

- The inevitable result of the constant cooling of the universe is,

$$\Delta U = 0 - W$$

$$\Delta U \langle 0$$

Energy Degradation of the Universe

HEAT DEATH OF THE UNIVERSE

COMING TO A THEATER NEAR YOU,

JUN 6, 2016

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Essential Idea:

- The first law of thermodynamics relates the change in internal energy of a system to the energy transferred and the work done. The entropy of the universe tends to a maximum.

QUESTIONS?

Homework

#29-37

"IT'S UNIFIED AND IT'S A THEORY, BUT IT'S NOT THE UNIFIED THEORY WE'VE ALL BEEN LOOKING FOR."

We Stopped Here on 2/8