Introduction to Physical Science

Thermodynamics

Presented by Robert Wagner

First Law of Thermodynamics

- Change in internal energy of a system is equal to the net heat transfer into the system minus the net work done by the system
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  - Conservation of energy for a system in thermal equilibrium

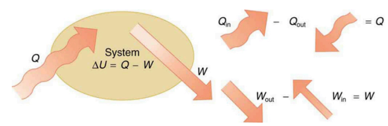
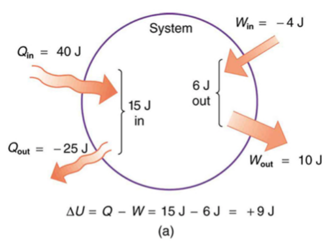


Figure 15.3 The first law of thermodynamics is the conservation-of-energy principle stated for a system where heat and work are the methods of transferring energy for a system in thermal equilibrium. Q represents the net heat transfer—it is the sum of all heat transfers into and out of the system. Q is positive for net heat transfer *into* the system. W is the total work done on and by the system. W is positive when more work is done *by* the system than on it. The change in the internal energy of the system, ΔU, is related to heat and work by the first law of thermodynamics, $\Delta U = Q - W$.

Example

- There is a heat transfer of 40.00 J to a system, while the system does 10.0 J of work. Later, there is heat transfer of 25.00 J out of the system while 4.00 J of work is done on the system. What is the net change in internal energy of the system?
  - Draw a sketch (if applicable)
  - Identify known values
  - Identify equation
  - Enter values in the equation and solve



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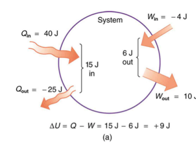


$Q_1 = 40.00\,J\,;\; Q_2 = -25.00\,J$
$W_1 = 10.00\,J\,;\; W_2 = -4.00\,J$

$Q_{net} = Q_1 + Q_2$
$W_{net} = W_1 + W_2$

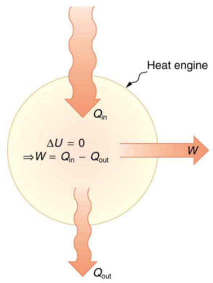
$Q = 40.00\,J - 25.00\,J = 15.00\,J$
$W = 10.00\,J - 4.00\,J = 6.00\,J$

$\Delta U = Q - W = 15.00\,J - 6.00\,J$

$\Delta U = 9.00\,J$

Heat Engine

- A device that uses heat energy to do work
  - Car engine
  - Steam turbines
- Work done depends on the path taken
  - PV diagram
  - Vertical paths - constant volume - isochoric
  - Horizontal paths - constant pressure - isobaric.



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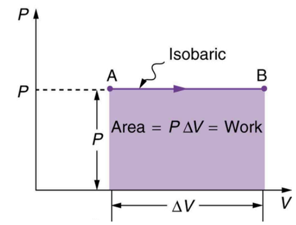

Example

- Calculate the total work done in the cyclical path ABCDA shown here. Calculate the work done along each segment to get the total work.
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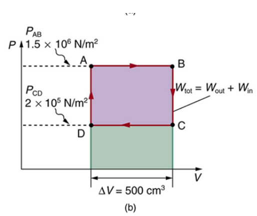

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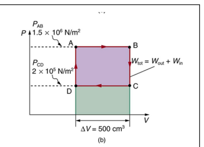


$P_{AB} = 1.50x10^6\ N/m^2\ ;\ P_{CD} = 2.00x10^5\ N/m^2$

$\Delta V = 500.\ cm^3 = 5.00x10^{-4}\ m^3$

$W_{AB} = P_{AB}\Delta V_{AB}$
$W_{AB} = (1.50x10^6\ N/m^2)(5.00x10^{-4}\ m^3) = 750.\ J$

$W_{BC} = P_{BC}\Delta V_{BC} = 0$

$W_{CD} = P_{CD}\Delta V_{CD}$
$W_{CD} = (2.00x10^6\ N/m^2)(-5.00x10^{-4}\ m^3) = -100.\ J$

$W_{DA} = P_{DA}\Delta V_{DA} = 0$

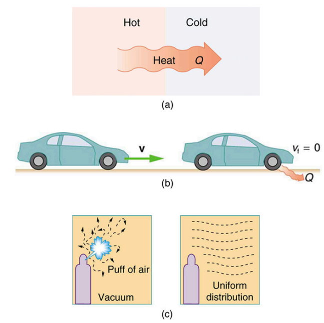
$W = W_{AB} + W_{BC} + W_{CD} + W_{DA} = 650.\ J$

Reversible Processes

- Reversible process - the system and environment can return to their original states by following the reverse path
- When dissipative processes like friction or turbulence exist, a process cannot be reversible

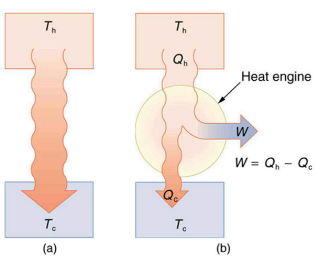
Second Law of Thermodynamics

- Many process occur spontaneously in one direction only
  - They are irreversible processes
- Heat will never transfer spontaneously from a cool object to a hot one
- Mechanical energy can be completely converted to thermal energy, but the reverse cannot occur
- Air will spread through a container, but not group in a corner



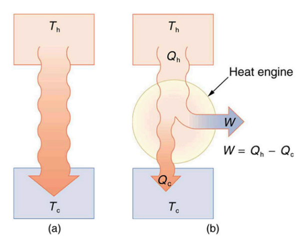
Second Law of Thermodynamics (2)

- 1st Expression
  - Heat transfer occurs spontaneously from higher to lower temperature bodies, but never spontaneously in the reverse direction.
- Heat Engines
  - Want high efficiency
- 2nd expression
  - It is impossible for any system for heat transfer from a reservoir to completely convert work in a cyclical process in which the system returns to its original state.



Cyclical Processes

- A cyclical process brings a system back to its original state at the end of each cycle.
  -
- Conversion efficiency: ratio of what we get to what is input
  -
- Efficiency can never be 1. Some energy is always lost



Example

- A coal power plant uses heat transfer from burning coal to turn turbines which generate electricity. Suppose in a single day, the station has $2.50\text{x}10^{14}$ J heat transfer from coal and $1.48\text{x}10^{14}$ J heat transfer into the environment. What is the work done by the power station? What is the efficiency of the power station?
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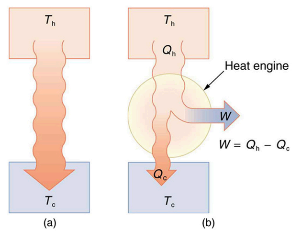

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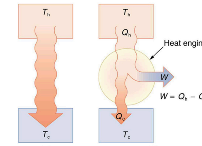
Example



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$$Q_h = 2.50x10^{14}\,J\;;\;Q_c = 1.48x10^{14}\,J$$

$$W = Q_h - Q_c$$

$$W = 2.50x10^{14}\,J - 1.48x10^{14}\,J = 1.02x10^{14}\,J$$

$$Eff = \frac{W}{Q_h}$$

$$Eff = \frac{1.02x10^{14}\,J}{2.50x10^{14}\,J} = 0.408 = 40.8\,\%$$

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Summary

- 1st Law: Law of conservation of energy. Change in energy = energy in less the energy out
- Heat engines are devices that we use to do work on a system
- 2nd Law: A system can never convert heat to work with 100% efficiency