CHAPTER: The, 0th, first and Second Law of Thermodynamics

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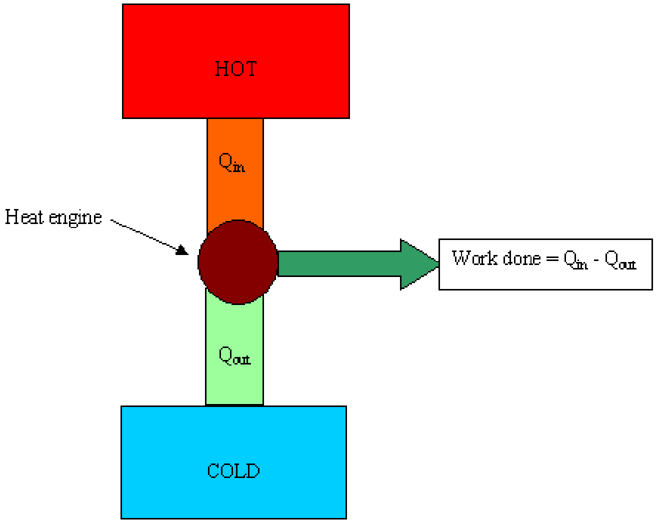
CREDITS

- Physics for scientists and engineers, Serway
- http://ebooks.bfwpub.com/
- http://hyperphysics.phy-astr.gsu.edu
- www.prenhall.com/esm_wilson_physics
- http://www.walter-fendt.de/ph11e
- http://www.lon-capa.org/~mmp/
- SERWAY COLLEGE PHYSICS 7E MEDIA LIBRARY

Objectives I

- Examine the 0th, first and 2nd laws of thermodynamics
    - How it relates directly to heat engines as well as refrigerators.
- Define irreversibility and entropy
    - how entropy relates to the availability of energy, disorder, and probability.
- Investigate and examine the functioning of an ideal heat engine:
    - the Carnot engine;



    - Define the efficiency of a thermal engine;
- Interpret and apply the laws of thermodynamics to explain natural phenomena;
- Calculating the Work Done by a Heat Engine Operating in a Cycle;
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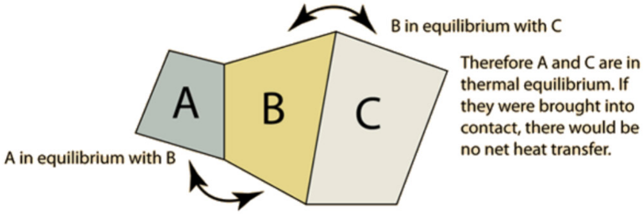
Zeroth Law of Thermodynamics



Therefore A and C are in thermal equilibrium. If they were brought into contact, there would be no net heat transfer.

- The "zeroth law" states that if two systems are at the same time in thermal equilibrium with a third system, they are in thermal equilibrium with each other.
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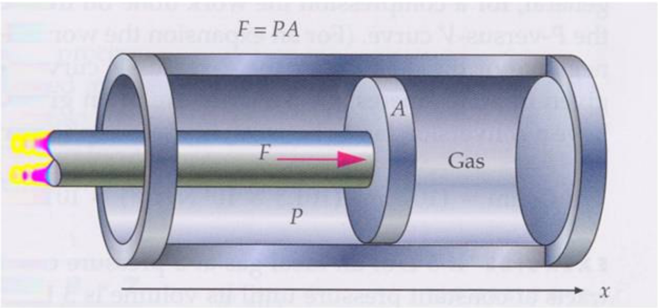
Work done by a gas



$W = F\,\Delta x \rightarrow$

$W = pA\,\Delta x \rightarrow$

$W = p\,\Delta V \rightarrow$

-

Work done during isothermal expansion

- An ideal gas and the process is quasi-static,
  - the ideal gas law is valid for each point on the path.
- The work equals the negative of the area under the PV diagram.
- the gas expands, $V_{f>}V_i$ value of the work done on the gas is negative.
- If the gas is compressed, $V_{f<}V_i$ and the value of the work done on the gas is positive. →
- W is defined as $+$ if the work is done by the system, gas
-

Heat as a form of energy

$Q{=}mc\Delta T$

- where c is the specific heat OR

$Q{=}C\Delta T$

- where C is the Heat capacity
-

First principle of thermodynamics

- The First Law of Thermodynamics is a special case of the Law of Conservation of Energy.
    - It is a special cas when only the internal energy changes and the only energy transfers are by heat and work.
- The First Law of Thermodynamics states that

  $\Delta E_{int}=Q_{in}+W_{on}$

  $\Delta E_{int}=Q_{in}-W_{by}$
- The internal energy, E_{int}, is a state variable.
    - depends on T only

  $E_{int}=f(T)=\frac{3}{2}k_B T$
- for and ideal $mono$atomic gas
-

First principle of thermodynamics

$Q_{\text{in}}=\Delta E+W_{\text{by system}} \rightarrow$

- When heat is added to a thermodynamic system - gas:
- The internal energy of the system increases, $\Delta E_{\text{internal}} > 0$
- The system is doing work
-

Energy conservation for Specific processes: isobaric

- Constant pressure
    - $\Delta p = 0 \rightarrow p = cst$

  $W = P(V_{f-}V_i)$ and

  $\Delta E_{int}=Q+W$
-

Energy conservation for Specific processes: isothermal

- Constant pressure
    - $\Delta\, T = 0 \rightarrow T = cst$

  $\Delta E_{int}=0$
  $\Delta E_{int}=Q+W \rightarrow Q=-W$
-

Specific processes - Summary

- Adiabatic: No heat exchanged $Q = 0 \rightarrow$
  $\Delta E_{int}=W$
- Isobaric: Constant pressure
  $W = p\left(V_{f} - V_{i}\right) \;\; and$
  $\Delta E_{int}=Q+W$
- Isothermal: Constant temperature
  $\Delta E_{int}=0 \rightarrow$
  $Q=-W$
-

Heat, Work, sign convention

- $Q_{\text{given off by gas}} < 0$
- $Q_{\text{out}} < 0$
- E_{internal} internal energy of a system and the heat, $Q_{\text{gained by system}}$ gained by the system → a beaker of water on a hot plate.
- When the hot plate is turned on, the system gains heat, Q_{in} from its surroundings.
- As a result, both the temperature and the internal energy of the system increase, and $\Delta E > 0$
- Heat absorbed by the system = positive, $Q_{\text{gained by system}} > 0$
- Work done on the system = positive,
-

Example heat being added to a system, calculating change in internal energy

$9000J$ of heat, Q_{in} is added to a gas; The gas expands and does $W_{\text{by gas}} = 2000J$ of work. Calculate the change in the internal energy of the gas, E_{internal} ?

$Q_{\text{in}}=9000J$

$W_{\text{by gas}} = 2000J$

$\Delta E=Q_{\text{in}}+W_{\text{on the system}} \rightarrow$

$\Delta E=Q_{\text{in}}-W_{\text{by the system}} \rightarrow$

$\Delta E=9000J-2000J=7000J$

-

Ideal gas law: applications

- 1 mole , $n = 1$, of an ideal monatomic gas undergoes the following process: It starts in the state (p_o, V_o) It expands isobarically to the state $(p_o, 5V_o)$ It is heated at constant volume (isochorically) to $(7p_o, 5V_o)$
- Plot this on a PV diagram
- What is the temperature difference between the initial and the final state?
- What is the internal energy change?
- What is the total heat flow into the gas?
-

Ideal gas law: applications

- 1 mol $n = 1$ of an ideal monatomic ....

  1) $p_o V_o = nRT_o$

  2) $p_f V_f = nRT_f \rightarrow$

  subtracting equation 1) from equation 2 →

  $p_f V_f - p_i V_i = nR(T_f - T_i) \rightarrow$

  $\Delta T = \frac{p_f . V_{f-} p_i \cdot V_i}{nR} = \frac{7p_o \cdot 5V_o - p_o \cdot V_o}{nR} == 34 P_o \frac{V_o}{nR}$

  $\Delta E_{int} = \frac{3}{2} k_B \Delta T$

  $\Delta E_{int} = Q_{in} + W_{on} \rightarrow$

  $Q = ?$
-

Task First Law of thermodynamics

- A gas undergoes an isobarric expansion from $V_0 = 1m^3$ to $V_1 = 5 \cdot V_0$. The gas is at a pressure: $p_o = 2atm = 200000\,\frac{N}{m^2}$. Calculate the $W_{\text{ by gas during expansion}}$ and $\Delta\, E_{int}$.
-
-
-

Task First Law of thermodynamics

$V_0 = 1m^3$ $p_1 = p_o \rightarrow$ isobarric expansion $V_1 = 5 \cdot V_0 = 5 \cdot 1m^3 = 5m^3$

-
-

SOLUTION: Task First Law of thermodynamics

$$p_2 = 7 \cdot p_1 = 7 \cdot p_0 = 7 \cdot 2atm = 14atm = 7 \cdot 200000 = 1400000\frac{N}{m^2}$$

$$W_{\text{ by gas during expansion}} = p \cdot\ \Delta\, V = 200000\,\frac{N}{m^2} \cdot (5-1)m^3 = 800000J = \ \rightarrow N \cdot m = J$$

$$\Delta\, T = ?$$

$$p_0 \cdot V_0 = nR \cdot T_o \rightarrow T_o = \frac{p_0 V_0}{nR} = \frac{200000\,\frac{N}{m^2} \cdot 1m^3}{1 \cdot 8.31} \rightarrow 24067^oK$$

-

SOLUTION: Task First Law of thermodynamics

$T_1 = ?$

$$p_1 V_1 = nR \cdot T_1 \rightarrow T_1 = \frac{p_1 V_1}{nR} = \frac{200000 \frac{N}{m^2} \cdot 4m^3}{1 \cdot 8.31} \rightarrow 96269.5^o K$$

$$\Delta\, E_{int} = \frac{3}{2} k_B \cdot \; \Delta\, T = \frac{3}{2} k_B \cdot (96269.5 - 96269.5) = 1.5 \cdot 1.3 \cdot 10^{-23} \cdot \left(72 \cdot 10^3\right) \rightarrow J$$

-

final Volume for an isobarric process

TASK2: Calculate the final Volume for an isobarric process, $p = cst$, if initial $T_i = 24^0 C$ and final $T_{f=}78^0 C$. V_i that the gas occupies is $0.4m^3$.

$p_i \cdot V_i = nR \cdot T_i$

$p_{f\cdot} V_{f=} nR \cdot T_{f\rightarrow}$

$p_i = p_f$

$$\frac{p_i \cdot V_i}{p_{f\cdot} V_f} = \frac{nR \cdot T_i}{nR \cdot T_f}$$

$$V_{f=} \left(\frac{p_i}{p_{f\cdot}} V_i\right) \cdot \frac{T_f}{T_i}$$

$$V_{f=} \frac{n \cdot RT_f}{p_f}$$

-

Specific processes: adiabatic

Tire pressure problem:

$$200000 \cdot \frac{50 + 273.15}{20 + 273.15} = 220467.33\,\frac{N}{m^2}$$

Task 3:

Calculate final pressure p_F if Volume increases by $10\,\%$

$$p_F = p_i \cdot \frac{T_f}{T_i} \cdot \frac{1}{1.1}$$

$$p_F = 20000 \cdot \frac{50 + 273.15}{20 + 273.15} \cdot \frac{1}{1.1}$$

-

Specific processes

isothermal → $\frac{p_f}{p_i} = 2 = \frac{V_i}{V_f} = \frac{4}{2}$

adiabatic → $\frac{p_f}{p_i} = 2 = \left(\frac{V_i}{V_f}\right)^{\gamma} = \left(\frac{V_i}{V_f}\right)^{1.4}$

Doubling the pressure in both an isothermal and an adiabatic process would produce what change in Volume ? What would the ratio of $\frac{V_i}{V_{f\,\text{be?}}}$

By what factor would the volume change?

$$\left(\frac{V_i}{V_f}\right)_{\text{isothermal}} = \frac{1}{2}$$

$$\left(\frac{V_i}{V_f}\right)_{\text{adiabatic}} = \left(\frac{V_i}{V_f}\right)^{1.4} < \ > \frac{1}{2}$$

-

Specific processes: adiabatic

A diatomic gas, $\gamma = \frac{C_P}{C_v} = 1.4$, gas at an initial pressure of $3atm$ occupying an initial volume $V_i = 2L$ undergoes an isothermal increase in pressure. Final pressure is twice the initial pressure. Calculate the final volume, V_F. For your info $\gamma_{\text{ideal monoatomic gas}} = 1.4$ Known:

$p_i = 2atm$

$V_i = 2L$

$p_{f=}6atm$

Required: $V_{\text{f, isothermal}} = ?$

$p_i \cdot V_i = p_f . V_f \rightarrow$

$$V_{f=}V_i \cdot \frac{p_i}{p_f}$$

$$V_{f=}2 \cdot \frac{3}{6} = 1L \ \rightarrow L \cdot \frac{atm}{atm}$$

-

Specific processes: adiabatic

A monoatomic gas, $\gamma = \frac{C_P}{C_v} = 1.4$, at an initial pressure of $3atm$ occupying an initial volume $V_i = 2L$ undergoes an adiabatic transformation, increase in pressure. Final pressure is twice the initial pressure. Calculate the final volume, V_F. For your info $\gamma_{\text{ideal monoatomic gas}} = 1.4$

$p_i = 2atm$

$V_i = 2L$

$p_{f=} 6atm$

Required: $V_{\text{f, adiabatic}} = ?$

$$p_i \cdot V_i^{\gamma} = p_f . V_f^{\gamma} \rightarrow$$

$$p_i \cdot V_i^{1.4} = p_f . V_f^{1.4} \rightarrow$$

$$V_f^{\gamma} = V_i^{\gamma} \cdot \frac{p_i}{p_f} \rightarrow$$

$$V_{f=} V_i^{\gamma} \cdot \frac{p_i^{\frac{1}{}}}{p_f^{\gamma}}$$

$$V_{f=} 2 \cdot \frac{3}{6} = 1L \rightarrow L \cdot \frac{atm}{atm}$$

-

Specific processes: adiabatic

adiabatic → no heat is transferred in or out → $Q = 0$

$pV = nRT$ ← isochoric, isobarric, isothermal

adiabatic →equation of state
$pV^{\gamma} = cst$ ← adiabatic
$pV = cst$ ← isothermal

$$V = \frac{nRT}{p}$$
$$\gamma = \frac{C_p}{C_V} = 1.4$$diatomic gas

$Q = m \cdot c\,\Delta\,T$
$pT^{\gamma-1} = cst$

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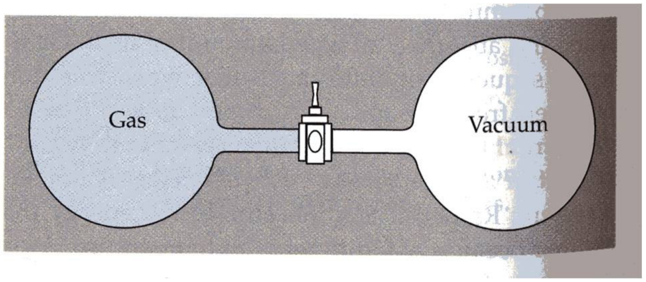
Free expansion, adiabatic no heat exchanged



- Adiabatic free expansion, expansion in vacuum
    - No heat exchanged $Q = 0$

  ΔE_{int}=Q_{in}+W_{on} since $Q = 0$ →

  ΔE_{int}=W
- Insulating walls → no heat enters, i.e., $Q = 0$
- NO work done, i.e., $W = 0$ →
- $\Delta\ E_{int} = 0$
    - Ideal gas (low pressure): T observed not to change
- Real gas: T decreases but $\Delta\ E_{int} = 0$
-

Specific processes: adiabatic

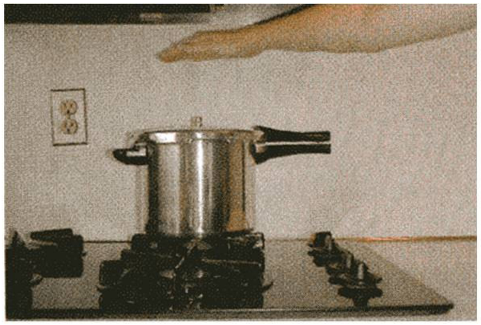
- Adiabatic
    - No heat exchanged $Q = 0$

  ΔE_{int}=Q_{in}+W_{on} since $Q = 0$ →

  ΔE_{int}=W_{on}
-

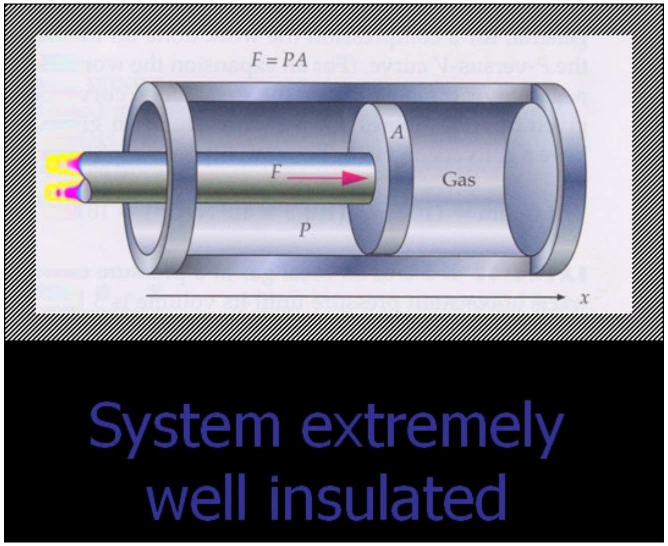
Examples adiabatic processes

- The expansion of hot gases in an internal combustion engine



... or process happens very quickly

- The liquefaction of gases in a cooling system
    - or process happens very quickly



System extremely well insulated

- The compression stroke in a diesel engine
- Adiabatic cooling occurs when the pressure of a substance is decreased as it does work on its surroundings.
    - Adiabatic cooling occurs in the Earth's atmosphere
        - this can form pileus or lenticular clouds if the air is cooled below the dew point.
- When the pressure applied on a parcel of air decreases, the air in the parcel is allowed to expand;
    - as the volume increases, the temperature falls and internal energy decreases.
-

Adiabatic process

- Reversible adiabatic compression of ideal gas:
    - no heat flows into or out of system

  $\Delta E = C_V \Delta T = -p \Delta V =$

  $pV^{\gamma} = cst$

  $TV^{\gamma-1} = cst$

  $\gamma = \frac{C_P}{C_V} = 1.67$ for a monoatomic gas and $\gamma = 1.4$ for an ideal diatomic gas!
-

Adiabatic cooling: processes

- Rising moist air cools due to adiabatic expansion of the air.

- Cooling causes water vapour to condense into liquid droplets.
- Open a bottle of carbonated beverage;
    - a mini cloud forms
- Air compressors (petrol stations, scuba tanks): output air is warmer than air entering compressor
- Compression and expansion strokes in combustion engine
-

Example adiabatic process

- 1 mol of a diatomic gas (consider it's a diatomic ideal gas, $\rightarrow \gamma = 1.4$) is compressed adiabatically and reversibly from an initial pressure of $1atm$ and a volume of $4L$ at temperature $20C^o$ to half its original volume. Find a) the final pressure, b) the final temperature, and c) the work done on the gas.
  $TV^{\gamma-1}$=cst or
  pV^{γ}=cst
  $\gamma = 1.4$,
  $R =$ universal gas constant $= 8.3145\,\frac{J}{mol \cdot K}$, $C_V = \frac{5}{2} \cdot R = \frac{5}{2} \cdot 8.3145\,\frac{J}{mol \cdot K} = 20.78\frac{J}{mol \cdot K}$
  $p_i = 1atm$
  $V_i = 4L$
  $V_{f=}\ \frac{4L}{2}$
  $p_{f=}\,?$
  $p_i V_i^{\gamma} = p_f V_f^{\gamma} \rightarrow p_f = \left(\frac{V_i}{V_f}\right)^{\gamma} \cdot p_i$
  $p_f = \left(\frac{4L}{2L}\right)^{1.4} \cdot 1atm = 2.64atm$
-

Example adiabatic process, calculating final temperature:

$$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1} \rightarrow$$

$$T_f = \frac{T_i \cdot V_i^{\gamma-1}}{V_f^{\gamma-1}} = T_i \cdot \left(\frac{V_i}{V_f}\right)^{\gamma-1}$$

$$T_f = 20^o C \cdot \left(\frac{4}{2}\right)^{1.4-1} = 26.4^o C$$

- Since it's and adiabatic process, $Q = 0 \rightarrow$ Fromthe forst principle of thermodynamics, Delta E_(i\n\t)=Q+Wrarr

$$\Delta E_{int} = \frac{3}{2} C_V \Delta T = \frac{3}{2} C_V T_f - T_i = W \rightarrow$$

$$W = \frac{3}{2} \cdot 20.78 \cdot \left((26.4 + 273^o K) - (20 + 273^o K)\right)$$

$$W = \frac{3}{2} \cdot 20.78 \cdot \left((26.4 + 273) - (20 + 273)\right) = 199.43 J$$

-

Example adiabatic process

Link: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/adiab.html#c3

- 1 mole of a diatomic gas is compressed adiabatically and reversibly from an initial pressure of $6\,.\,atm$ and a volume of $4L$ at temperature $20C^o$ to half its original volume.
  Find a) the final pressure, b) the final temperature, and c) the work done on the gas.
- a) $p_{f\,=}p_i\cdot\frac{V_i^\gamma}{V_f^\gamma}$

  $$p_{f\,=}(6atm)\cdot\left(\frac{4L}{2L}\right)^{1.4}=\;15.83atm$$
- b) $T_{f\,=}T_i\cdot\frac{V_i^\gamma}{V_f^\gamma}$

  $$T_{f\,=}(20^oC+273.15)\cdot\left(\frac{4L}{2L}\right)^{1.4}=\;113.663\text{^oC}$$

  $$T_{f\,=}(20+273.15)\cdot\left(\frac{4}{2}\right)^{1.4-1}=386.813K=113.663^oC$$
- c) $\Delta\,E=\;\Delta\,U=\frac{p_{\text{final}}\cdot V_{\text{final}}-p_{\text{initial}*}V_{\text{initial}}}{\gamma-1}$

  $$\Delta\,E=\;\Delta\,U=\frac{15.83atm\cdot 101000\,\frac{\frac{N}{m^2}}{atm}\cdot 2L-6atm\cdot 101000\,\frac{\frac{N}{m^2}}{atm}\cdot 4L}{1.4-1}=1934150\,.\,J=1934.150kJ$$

Example: Big Bang Expansion as an adiabatic process

- If the radius of the Universe is $r_U = 1.4 \cdot 10^{26} m$ and the Temperature, $T = 2.7^o K$ calculate the initial temperature when the radius was $r_i = 2 \cdot 10^{-2} m$. Use $\gamma = 1.67$. What was the initial pressure ?
- Solution:

  $T_i \cdot V_i^{\gamma-1} = T_f . V_f^{\gamma-1} \rightarrow T_i$

  $$T_i = T_f . \frac{V_f^{\gamma-1}}{V_i^{\gamma-1}}$$

  $$T_i = T_f . \frac{\left(\left(\left(\frac{4}{3} \cdot \pi\right) \cdot r_f^3\right)\right)^{\gamma-1}}{\left(\left(\left(\frac{4}{3} \cdot \pi\right) \cdot r_i^3\right)\right)^{\gamma-1}}$$

  $$T_i = T_f . \frac{\left(r_f^3\right)^{\gamma-1}}{r_i^3 \wedge (\gamma - 1)}$$

  $$T_i = 2.7 \cdot \frac{\left(\left(1.4 \cdot 10^{26}\right)^3\right)^{1.67-1}}{\left(\left(2 \cdot 10^{-2}\right)^3\right)^{1.67-1}}$$

  $$T_i = 2.7 \cdot \frac{\left(\left(1.4 \cdot 10^{26}\right)\right)^{3 \cdot 1.67-3}}{\left(\left(2 \cdot 10^{-2}\right)\right)^{3 \cdot 1.67-3}} = 2.5 \cdot 10^{+56} K$$
- Classroom Task: Why would the expansion be considered an adiabatic process ?
  - Hint: What is an adiabatic process ?
-

Example: Big Bang Expansion as an adiabatic process

$$T_i = 2.7 \cdot \frac{\left(\left(1.4 \cdot 10^{26}\right)^3\right)^{1.67-1}}{\left(\left(2 \cdot 10^{-2}\right)^3\right)^{1.67-1}}$$

$$T_i = 2.7 \cdot \frac{\left(\left(1.4 \cdot 10^{26}\right)\right)^{3 \cdot 1.67-3}}{\left(\left(2 \cdot 10^{-2}\right)\right)^{3 \cdot 1.67-3}} = 2.5 \cdot 10^{+}56K$$

- Classroom Task: Why would the expansion be considered an adiabatic process ?
    - Hint: What is an adiabatic process ?
-

Sample problem

$n = \text{no of moles} = 1$ of a gas undergoes a transformation from :
$p_0 = 1.2atm$

$V_0 = 2.3L$ to $p_{f=}7atm, V_{f=}1.2L, T_f$.
Calculate $T_f,\ \Delta E_{\text{int}}, W_{\text{by gas}}$

$$T_F = \frac{p_F \cdot V_F}{nR} = \frac{7 \cdot 1.2 \cdot 5 \cdot 2.3}{1 \cdot 0.083} \rightarrow^o K$$

$$\Delta E_{\text{int}} = Q_{\text{in}} - W_{\text{by}} = \frac{3}{2} \cdot k_B \cdot \ \Delta T$$

$$E_{\text{int}} = \frac{3}{2} \cdot 1.38 \cdot 10^{-23} \cdot (T_F - T_0) = ?$$

$$T_0 = 57^oC \rightarrow^o K = 57 + 273.15 = ?$$

$$W_{\text{by}} = p \cdot \ \Delta V = p_0(5V_0 - V_0) = 1.2atm \cdot 4 \cdot 2.3L = ?$$

$$Q_{\text{in}} = \ \Delta E_{\text{int}} + W_{\text{by}}$$

$$k_B = 1.38 \cdot 10^{-23} \frac{J}{{}^\wedge oK} \rightarrow 1.38 \cdot 10^{-25} \frac{L \cdot atm}{{}^\wedge oK}$$

$$n_{\text{moles}} \cdot R = k_B \cdot N_{\text{atoms}}$$

-

Sample problem adiabatic transformation

$n_{\text{moles=}}1$

$\gamma = 1.4$

$p_o = 1atm$

$V_0 = 4L$

$T_o = 20C^o = 273 + 20^oK$

$V_{f=}2L$

$p_F V_f^\gamma = p_o V_o^\gamma$

$p_{f=}p_o\left(\frac{V_o}{V_f}\right)^{1.4} = 1atm \cdot \left(\frac{4L}{2L}\right)^{1.4} = 2.63atm$

-

Sample problem adiabatic transformation

$T_F = ?$

$W_{\text{on}} = ?$

$T_0 V_0^{\gamma-1} = T_f V_f^{\gamma-1} \rightarrow$

$T_{f=} T_0 \left(\frac{V_o}{V_f}\right)^{1.4-1} = T_0 \left(\frac{V_o}{V_f}\right)^{0.4} = 293 \cdot \left(\frac{4}{2}\right)^{0.4} = 386.61^o K$

$R = 8.3145 \frac{J}{mol \cdot K}$

$W_{\text{on}} = -W_{\text{by}} = p \, \Delta \, V = 1atm\left(V_{f\,-}V_o\right) = 1atm \cdot (4L - 2L) \rightarrow \cdot 100J = N \cdot m$

-

Sample problem adiabatic transformation

$$p_iV_i^{\gamma} = p_fV_f^{\gamma}$$

$$T_iV_i^{\gamma-1} = T_{fV\_}f^{\gamma-1}$$

$$\gamma = 1.67$$

$$T_i = T_{f\cdot}\left(\frac{V_f}{V_i}\right)^{\gamma-1} = T_{f\cdot}\left(\frac{V_f}{V_i}\right)^{0.67} = 2.7^oK\cdot\left(\frac{\frac{4}{3}\pi\cdot\left(1.4\cdot10^{26}\right)^3}{\frac{4}{3}\pi\cdot\left(2\cdot10^{-2}\right)^3}\right)^{0.67} = 2.5\cdot10^{56}{}^\wedge oK$$

$$p_i = p_f$$

$$n_{\text{moles=}}1$$

$$\gamma = 1.4$$

$$p_o = 1atm$$

$$V_0 = 4L$$

$$T_o = 20C^o = 273 + 20^oK$$

$$V_{f=}2L$$

$$p_FV_f^{\gamma} = p_oV_o^{\gamma}$$

$$p_{f=}p_o\left(\frac{V_o}{V_f}\right)^{1.4} = 1atm\cdot\left(\frac{4L}{2L}\right)^{1.4} = 2.63atm$$

-

Sample problem 2

$$T_F = ?$$

$$W_{\text{on}} = ?$$

$$T_0V_0^{\gamma-1} = T_fV_f^{\gamma-1} \rightarrow$$

$$T_{f=}T_0\left(\frac{V_o}{V_f}\right)^{1.4-1} = T_0\left(\frac{V_o}{V_f}\right)^{0.4} = 293\cdot\left(\frac{4}{2}\right)^{0.4} = 386.61^oK$$

$$R = 8.3145\,\frac{J}{mol\cdot K} \rightarrow 0.082\,\frac{atm\cdot L}{K}$$

$$W_{\text{on}} = \; -W_{\text{by}} = p\,\Delta\,V = 1atm\left(V_{f-}V_o\right) = 1atm\cdot(2L-4L) \rightarrow \;\cdot 100J = N\cdot m$$

$$1atm = 101000 \rightarrow \frac{N}{m^2}$$

$$4L = 1000cm^3 = \frac{4}{10^6}m^3$$

-

Theory adiabatic ntransformation:

$W_{\text{by gas}} = p\,\Delta\,V \rightarrow\ \Delta\,V = 0 = \text{isochoric then} W_{\text{isochoric=cst V}} = 0$

$pV^{\gamma} = cst \text{for adiabatic} \rightarrow Q = 0$

$TV^{1.4-1} = cst$

for an adiabatic process for the same $\Delta\,p$

$V_{\text{f, adiabatic}} > V$
"f, isothermal"

-

conservation principle in thermodynamics

$$\Delta\, E_{\text{internal}} = Q_{\text{in}} + W_{\text{on}}$$

$$\Delta\, E_{\text{internal}} = \frac{3}{2} k_B \,\Delta\, T$$

$$W_{\text{on}} = \; - W_{\text{by}} = p\,\Delta\, V$$

$$Q = mc \cdot \;\Delta\, T$$

$$mc = C_V = \text{heat capacity}$$

$$C_P = \text{heat capacity for an isobarric process}$$

$$\gamma = 1.4, 1.6 \rightarrow \frac{C_p}{C_V}$$

-

Isolated systems definition

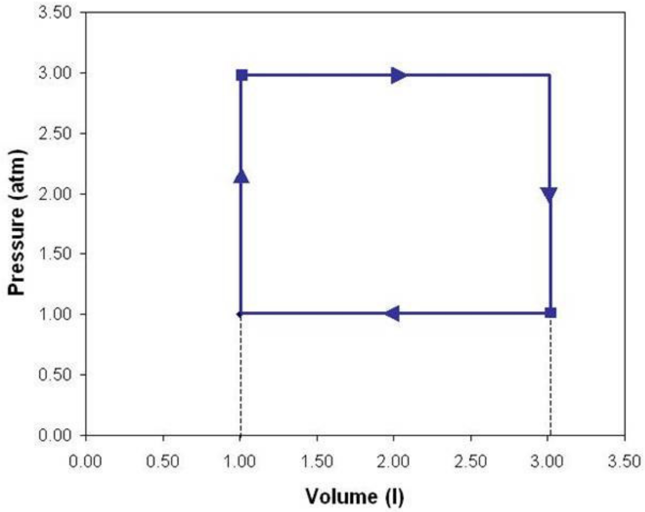
- An isolated system is one that does not interact with its surroundings.
- No energy transfer by heat takes place.
- The work done on the system is zero.
  $Q{=}W{=}0, \rightarrow$
  $\Delta E_{int}{=}0 \rightarrow E_{int}{=}cst$
- The internal energy of an isolated system remains constant
-

Cyclic processes, definition

- A cyclic process is one that starts and ends in the same state.
  - This process would not be isolated.
- On a PV diagram, a cyclic process appears as a closed curve.
- The internal energy must be zero since it is a state variable.
  $\Delta E_{int}=0 \rightarrow Q=-W$
- In a cyclic process, the net work done on the system per cycle equals the area enclosed by the path representing the process on a PV diagram.
-

Cyclic processes

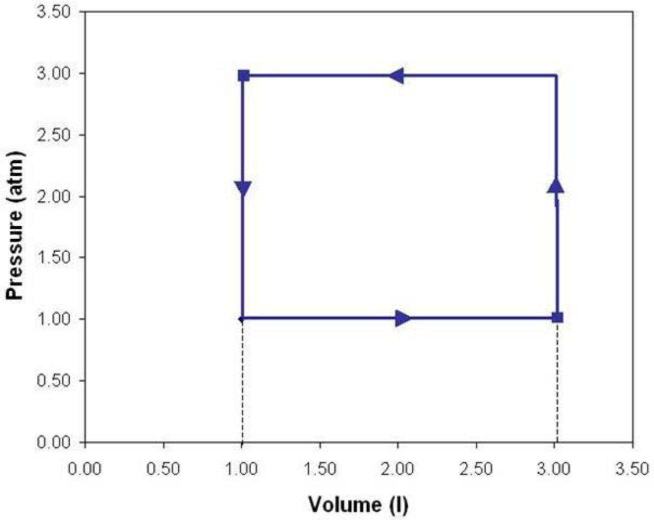
- Direction of path matters when calculating work



- Work done is positive $W > 0$
-

Cyclic processes

- Direction of path matters when calculating work



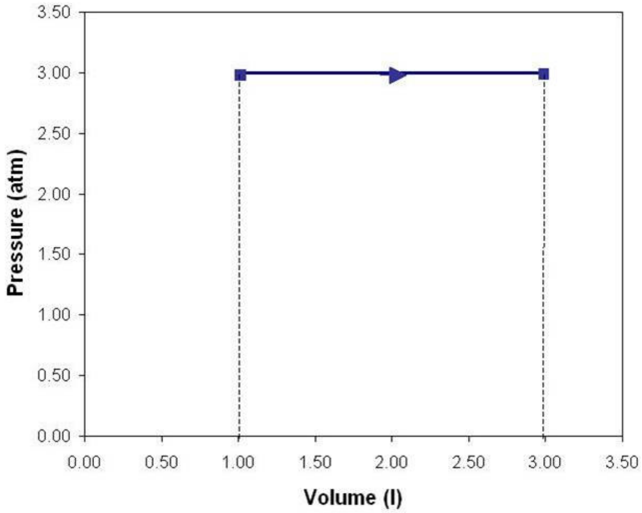
- Work done by gas is negative $W < 0$ →
- Work is done on gas!
-

Sign convention for work

- Gas expanding $p$cst$V$ positive → work done by gas:
  $W_{by}=F\,\Delta\,x=pA\,\Delta\,x=p\,\Delta\,V$
- Gas being compressed$p$cst$V$negative → work done on gas:
  $W_{on}=-W_{by}=-p\,\Delta\,V$
-

Classroom task 1

- Calculate the work done!



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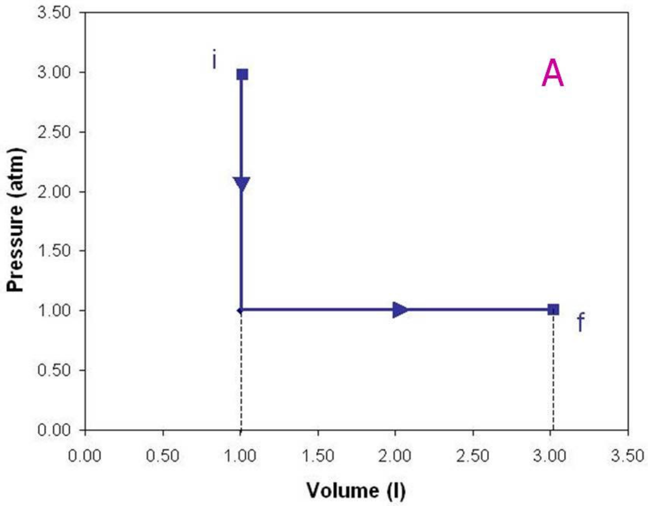
Classroom task 2

- Calculate the work done!



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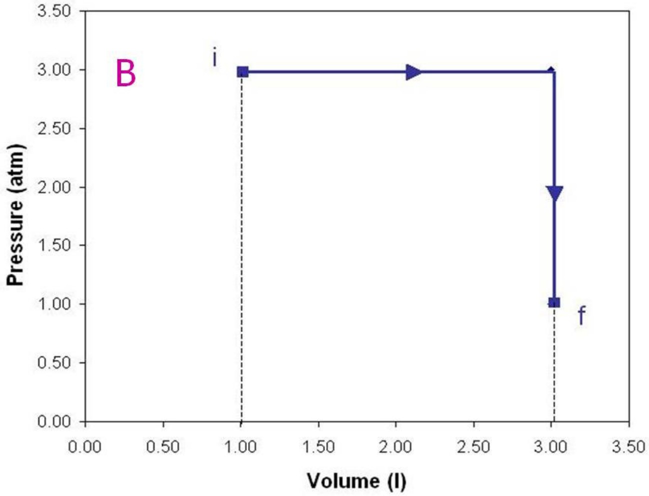
Classroom task 3

- Calculate the work done!



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Efficiency definition

- The efficiency is the work done divided by the heat absorbed:

$$\varepsilon=\frac{W}{Q_{absorbed}}=\frac{W}{Q_{in}}=\frac{W}{Q_{h,T}}$$

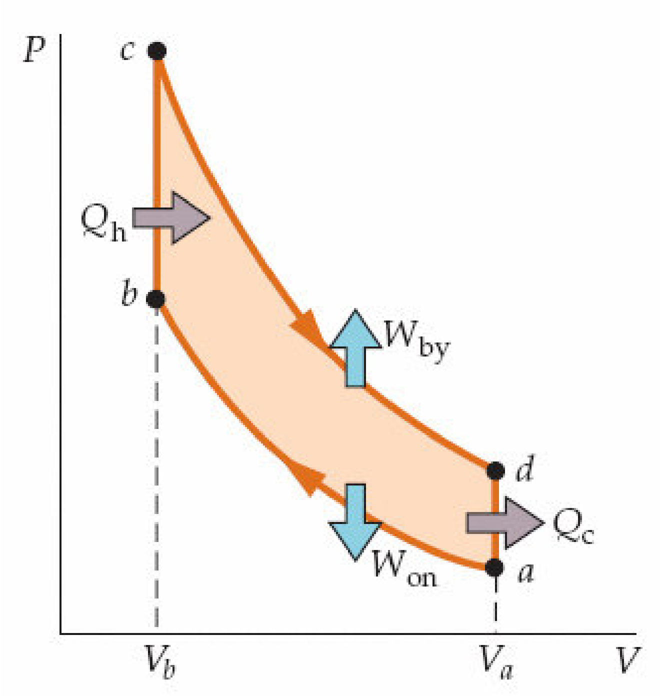
$$W=Q_{in}-Q_{out}=Q_{h,T}-Q_{c,T}$$

- $Q_{h,T}$ = heat absorbed from the high T reservoir
- $Q_{h,T}$ = heat given off to the low T reservoir →

$$\varepsilon=1-\frac{Q_{c,T}}{Q_{h,T}}$$

-

Otto cycle



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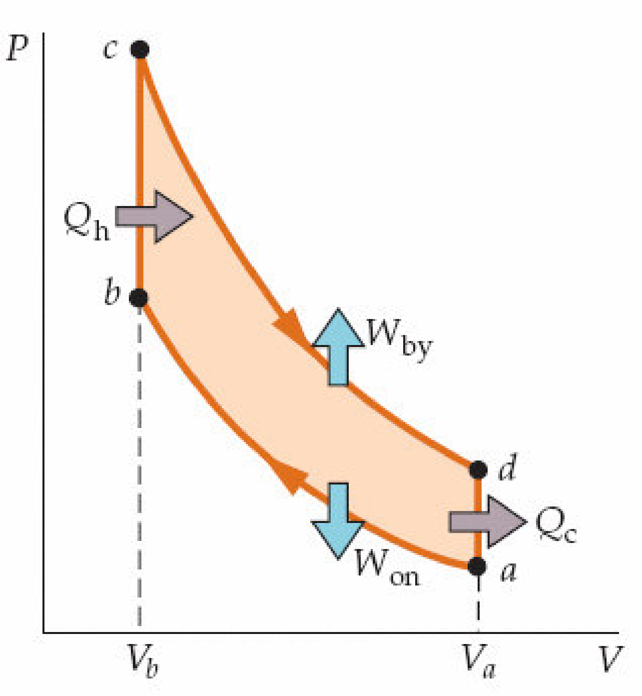
Otto cycle: Classroom task

- Identify the processes

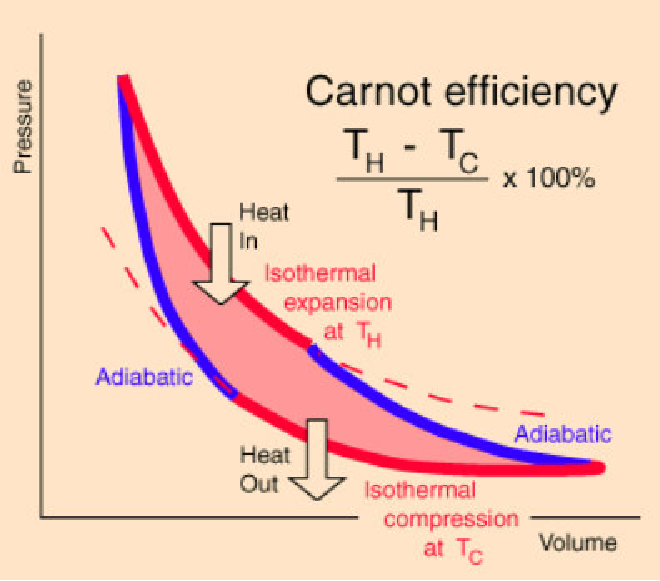


- Expansion
- Compression
- Iso...
-

Ch 19

- * Modern automobile gasoline engines have efficiencies of about 25%. About what percentage of the heat of combustion is not used for work but released as heat?
  $\varepsilon = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h} \rightarrow$
  $\frac{Q_c}{Q_h} = 1 - \varepsilon$
-

The efficiency of a Carnot engine

- $\varepsilon = 1 - \frac{Q_{c,T}}{Q_{h,T}}$


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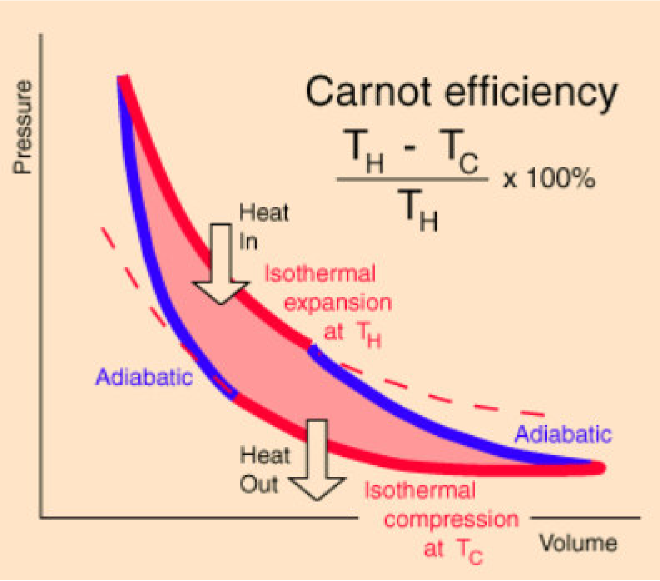
The efficiency of a Carnot engine



$$\varepsilon = 1 - \frac{Q_{c,T}}{Q_{h,T}}$$

-

The Carnot engine

$$\varepsilon_{Carnot} = 1 - \frac{T_c}{T_h}$$

-

ENTROPY OF AN IDEAL GAS

$\Delta\ E_{int}{=}Q_{rev}{+}W_{on}{=}Q_{rev}{-}p\ \Delta\ V\ \frac{Q_{rev}}{T}{=}\ \Delta\ S \rightarrow$ entropy →

$\Delta\ S{=}\frac{Q_{rev}}{T}$

- Entropy change of an ideal gas that goes from an initial state of volume V_1 and temperature T_1 to a final state of volume V_2 and temperature T_2.
-

Classroom Task

- $1.0L$ of air at $p_0\ = 6.0atm$ expands isothermally until the $p_2\ = 1.0atm$. It is then compressed isobarically to its initial volume and finally heated isochorically to its initial pressure. Draw this process on a $p - V$ diagram.

Example problem

- The pressure of an ideal gas inside a rigid container is reduced to one-half its initial value. In this process $800J$ of heat is removed ($\rightarrow Q < 0$) from the gas. a) What is the work done during this process? b) What is the change in internal energy of the gas during this process?
- rigid → $\ \Delta\ V = 0$.
  $W = p\ \Delta\ V = p \cdot 0 = 0 \rightarrow$
  $Q =\ \Delta\ E_{\text{int}}{+}W \rightarrow$
  $-800{=}\ \Delta\ E_{\text{int}}$
-
-