Thermodynamics
Heat & Work
The First Law of Thermodynamics

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De Anza College

April 29, 2020

Last time

- work, heat, and the first law of thermodynamics
- work done on a gas
- P-V diagrams

Overview

- more P-V diagrams
- new vocabulary for describing processes
- applying the first law in various cases

First Law of Thermodynamics

Reminder:

Internal energy, E_{int} or U

The energy that a system has as a result of its temperature and all other molecular motions, effects, and configurations, when viewed from a reference frame at rest with respect to the center of mass of the system.

1st Law

The change in the internal energy of a system is equal to the sum of the heat added to the system and the work done on the system.

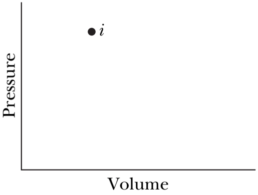
$$W + Q = \Delta E_{int}$$

This is just the conservation of energy assuming only the internal energy changes.

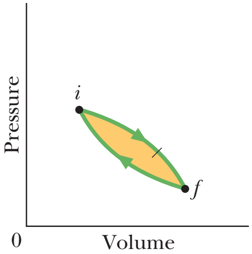
Applying the 1st Law

Some special cases of interest:

- for an isolated system,
  $W = Q = 0 \Rightarrow \Delta E_{\text{int}} = 0$



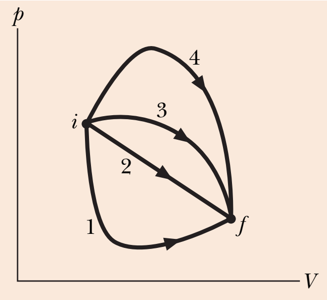
- for a process (V_i, P_i) to (V_i, P_i),
  a **cycle**, $\Delta E_{\text{int}} = 0 \Rightarrow Q = -W$



Applying the 1st Law & P-V diagrams questions

The figure shows four paths on a p-V diagram along which a gas can be taken from state i to state f. Rank the paths, greatest to least, according to

(a) the change ΔE_{int} in the internal energy of the gas,



A 1, 2, 3, 4

B 4, 3, 2, 1

C 1, 4, 3, 2

D all the same

[1]Based on question from Halliday, Resnick, and Walker, page 491.

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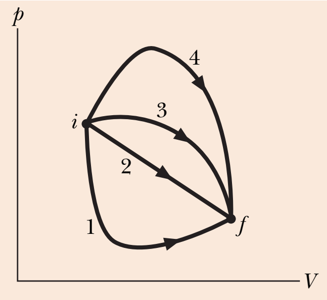

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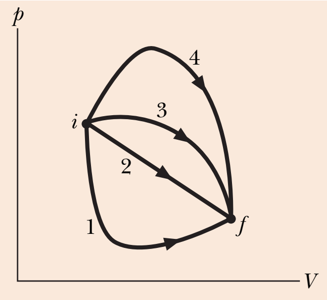
(b) the work W done **on** the gas,



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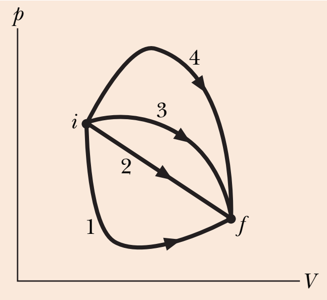
(b) the work W done **on** the gas, W is negative for them all.



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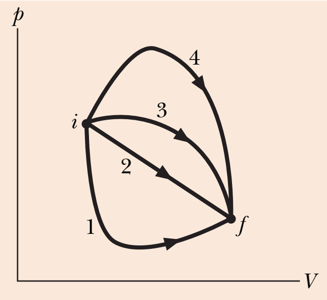

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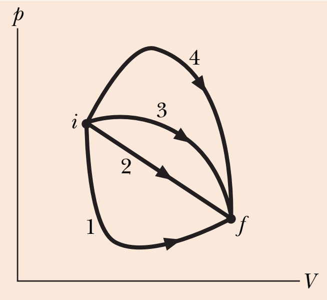

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Applying the 1st Law: new Vocabulary

There are infinitely many paths (V_i, P_i) to (V_f, P_f) that we might consider.

Ones that are of particular interest for modeling systems in engines, *etc.* are processes that keep one of the variables constant.

There is a technical name for each kind of process that keeps a variable constant.

Applying the 1st Law: new Vocabulary

Adiabatic process

is a process where no heat is transferred into or out of the system.

$$Q = 0$$

This type of transformation occurs when the gas is in a thermally insulated container, or the process is very rapid, so there is no time for heat transfer.

Since $Q = 0$:

$$\Delta E_{\text{int}} = W$$

Applying the 1st Law: new Vocabulary

Isobaric process

is a process that occurs at constant pressure.

$$P_i = P = P_f$$

This type of transformation occurs when the gas is free to expand or contract by coming into force equilibrium with a constant external environmental pressure.

In this case, the expression for work simplifies:

$$W = -\int_{V_i}^{V_f} P \, \mathrm{dV} = -P(V_f - V_i)$$

Applying the 1st Law: new Vocabulary

Isovolumetric process

is a process that occurs at constant volume.

$$V_i = V = V_f$$

In an isovolumetric process the work done is zero, since the volume never changes.

$$W = 0 \Rightarrow \Delta E_{\text{int}} = Q$$

(An isovolumetric process can also be called an "isochoric process".)

Applying the 1st Law: new Vocabulary

Isothermal process

is a process that occurs at constant temperature.

$$T_i = T = T_f$$

This kind of transformation is achieved by putting the system in thermal contact with a large constant-temperature reservoir.

In an isothermal process, assuming no change of phase (staying an ideal gas!):

$$\Delta E_{\text{int}} = 0$$

Isothermal Expansion of an Ideal Gas

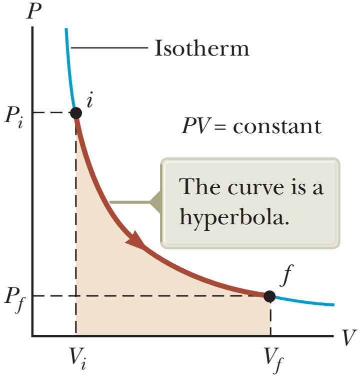
Since $\Delta T = 0$, $PV = nRT$ reduces to:

$$PV = a$$

where a is a constant. We could also write this as:

$$P = \frac{a}{V}$$

Plotting this function:



Isothermal Expansion of an Ideal Gas

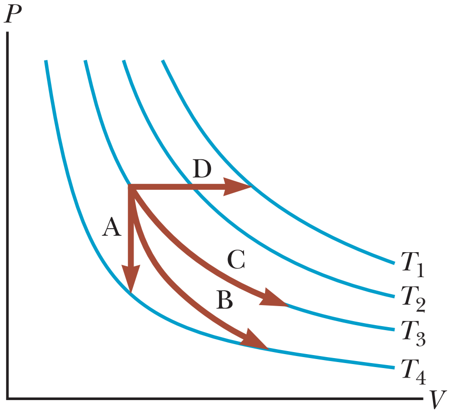
Since nRT is constant, the work done on the gas in an isothermal expansion is:

$$\begin{aligned} W &= -\int_{V_i}^{V_f} P\,\mathrm{dV} \\ &= -\int_{V_i}^{V_f} \frac{nRT}{V}\,\mathrm{dV} \\ &= -nRT\ln\left(\frac{V_f}{V_i}\right) \end{aligned}$$

$$W = nRT\ln\left(\frac{V_i}{V_f}\right)$$

Questions

Which path is isobaric?



[1]Based on Quick Quiz 20.4, Serway & Jewett, page 606.

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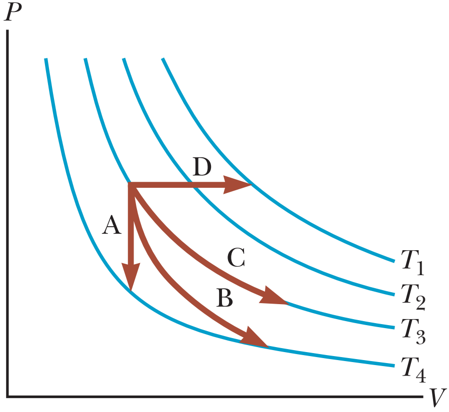
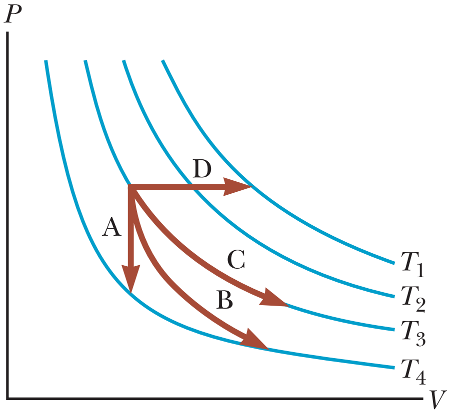


Path D.

[1]Based on Quick Quiz 20.4, Serway & Jewett, page 606.

Questions

Which path is isothermal?



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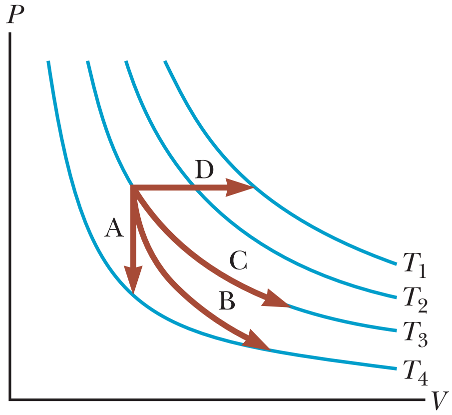
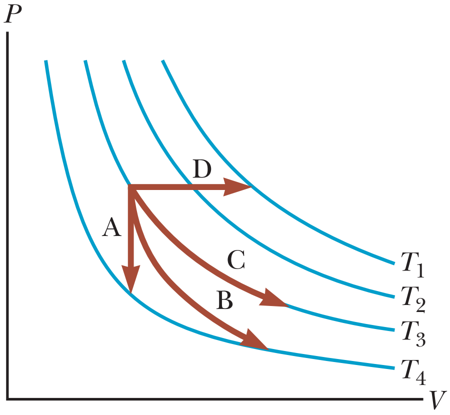


Path C.

[1]Based on Quick Quiz 20.4, Serway & Jewett, page 606.

Questions

Which path is isovolumetric?[1]



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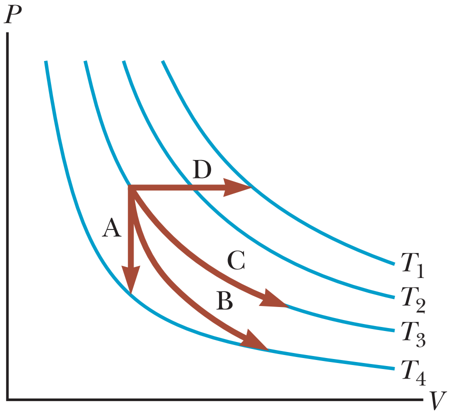
Which path is isovolumetric?

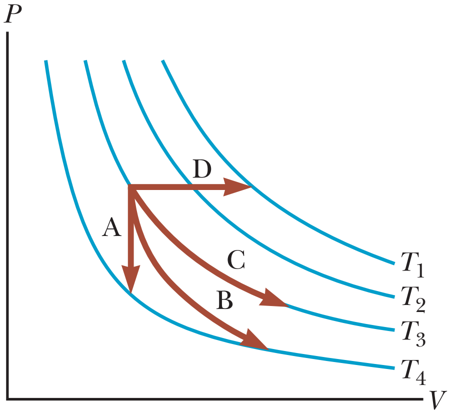


Path A.

[1]Based on Quick Quiz 20.4, Serway & Jewett, page 606.

Questions

Which path is adiabatic?



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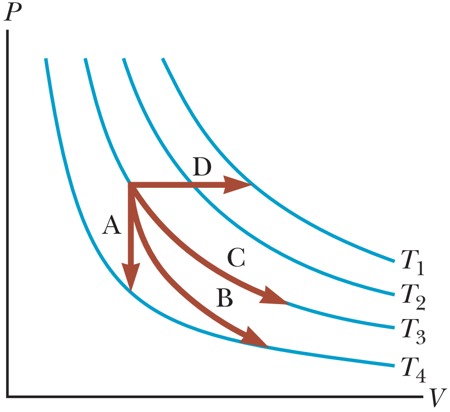

Path B.

[1]Based on Quick Quiz 20.4, Serway & Jewett, page 606.

Example 20.6: Boiling water

This example illustrates how we can apply these ideas to liquids and solids also, and even around phase changes, as long as we are careful.

Suppose 1.00 g of water vaporizes isobarically at atmospheric pressure (1.013×10^5 Pa).

Its volume in the liquid state is $V_i = V_{\text{liq}} = 1.00 \text{ cm}^3$, and its volume in the vapor state is $V_f = V_{\text{vap}} = 1671 \text{ cm}^3$.

Find the work done in the expansion and the change in internal energy of the system. Ignore any mixing of the steam and the surrounding air; imagine that the steam simply pushes the surrounding air out of the way.

Example 20.6: Boiling water

$V_i = V_{\text{liq}} = 1.00\ \text{cm}^3$
$V_f = V_{\text{vap}} = 1671\ \text{cm}^3$
$L_v = 2.26 \times 10^6\ \text{J/kg}$

Work done,

Example 20.6: Boiling water

$V_i = V_{\text{liq}} = 1.00 \text{ cm}^3$
$V_f = V_{\text{vap}} = 1671 \text{ cm}^3$
$L_v = 2.26 \times 10^6 \text{ J/kg}$

Work done, $\quad (W = \int P \, \text{dV})$

$$\begin{aligned} W &= -P(V_f - V_i) \\ &= -(1.013 \times 10^5 \text{ Pa})(1671 - 1.00) \times 10^{-6} \text{ m}^3 \\ &= -169 \text{ J} \end{aligned}$$

Internal energy, ΔE_{int}?

Example 20.6: Boiling water

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Internal energy, ΔE_{int}? Know W, must find Q:

$$\begin{aligned} Q &= L_v m \\ &= (2.26 \times 10^6\ \text{J/kg})(1^{-3}\ \text{kg}) \\ &= 2260\ \text{J} \end{aligned}$$

So,

$$\Delta E_{\text{int}} = W + Q = 2.09\ \text{kJ}$$

Summary

- P-V diagrams

Next Test Tuesday, May 5 (? TBC), on Ch19, 20.

Homework Serway & Jewett:

- Read chapter 20 and look at the examples.