Thermodynamics
Heat & Work
The First Law of Thermodynamics

Lana Sheridan

De Anza College

April 28, 2020

Last time

- more about phase changes

Overview

- work, heat, and the first law of thermodynamics
- P-V diagrams

Heat and Work

We now take a closer look at the first law of thermodynamics.

To do this, we will take a deeper look at work and heat.

We also need to consider our system more carefully.

Thermodynamic Equilibrium States

We will study **thermodynamic systems**.

These systems are in **thermodynamic equilibrium internally**.

Thermodynamic equilibrium state

a state of a system in which every part of the system will be at the same temperature, T, and if the system is a gas, at the same pressure, P.

In classical thermodynamics, it is a postulate that any system left isolated will come to a thermal equilibrium state given enough time, and then remain in that state.

Thermodynamic Equilibrium States

We will study **thermodynamic systems**.

These systems are in **thermodynamic equilibrium internally**.

Thermodynamic equilibrium state

a state of a system in which every part of the system will be at the same temperature, T, and if the system is a gas, at the same pressure, P.

In classical thermodynamics, it is a postulate that any system left isolated will come to a thermal equilibrium state given enough time, and then remain in that state.

In particular, for our present discussion we will be considering an **ideal gas**. (Can use $PV = nRT$.)

Ideal Gases

Ideal gas assumptions (kinetic theory model).

We make the following assumptions in the ideal gas model:

- the volume of the gas particles is negligible compared to the total gas volume
- molecules are identical hard spheres (will relax this later)
- collisions between molecules are elastic
- there are no intermolecular forces (aside from hard-sphere collisions)
- there are no long-range forces from the environment (can be relaxed)

A real gas is behaves as an idea gas when it is at high temperature and low density (far from condensation).

Variables

The variables we will use can be broken into types:

state variables – describe system's state / properties – T, P, V, and E_{int}.

transfer variables – describing energy transferred into our out of the system – Q, W

Variables

The variables we will use can be broken into types:

state variables – describe system's state / properties – T, P, V, and E_{int}.

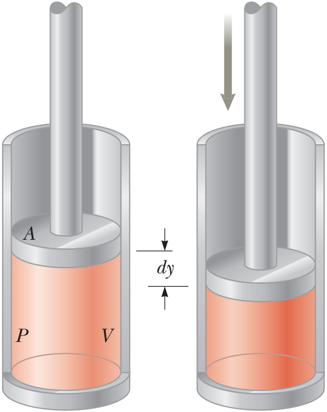
transfer variables – describing energy transferred into our out of the system – Q, W

intensive variables – variables that don't change value when the system is doubled in size – P, T, ρ, c

extensive variables – variables that double their value when the system is doubled in size – V, E_{int}, m, C

Work done on a gas

Imagine compressing or expanding a gas in a piston **quasi-statically** (meaning slowly enough so the gas remains in thermal equilibrium).

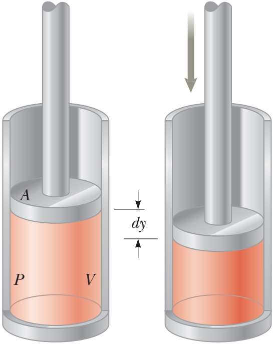


How much work is done **on** the gas?

---

[1] Figure form Serway & Jewett.

Work done on a gas



Definition of work:

$$W = \int \mathbf{F} \cdot \mathrm{d}\mathbf{r}$$

For this system:

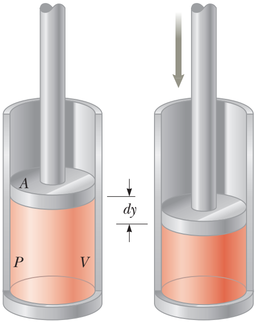
$$\begin{aligned} W &= \int (-F\mathbf{j}) \cdot \mathrm{d}y\,\mathbf{j} \\ &= -\int F\,\mathrm{d}y \\ &= -\int P\,A\,\mathrm{d}y \\ &= -\int P\,\mathrm{d}V \end{aligned}$$

$$\boxed{W = -\int_{V_i}^{V_f} P\,\mathrm{d}V}$$

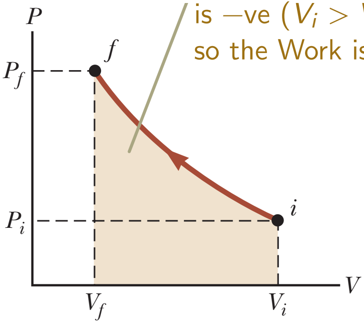
Work done on a gas

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

Here, the volume decreases, so the work done on the gas is positive.



The work done is the area under the *P*-*V* curve (with the appropriate sign).

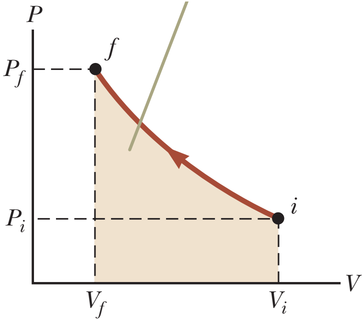


In this picture the area is −ve ($V_i > V_f$) so the Work is +ve.

Aside: *P*-*V* Diagrams

P-*V* diagrams are *very* useful in thermodynamics.

Example of a *P*-*V* diagram:



They are graphs of pressure vs volume for a fixed quantity (*n* moles) of an ideal gas.

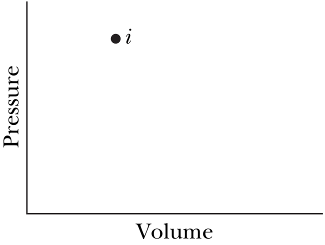
They contain a lot of information.

---

[1] Figure form Serway & Jewett, 9th ed, page 602.

Aside: P-V Diagrams

Example of a P-V diagram:



These diagrams

- represent the (thermodynamic) **equilibrium states** of the ideal gas sample,
- each point is a state,
- imply the temperature of a known sample, and
- show the internal energy of the gas. ($E_{\text{int}} \propto T$)

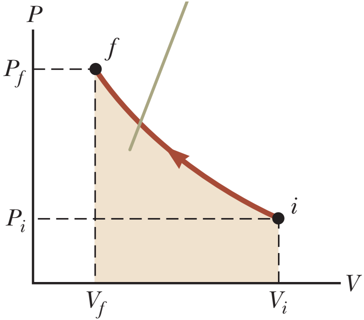
$$PV = nRT$$

---

[1] Figure (modified) from Halliday, Resnick, and Walker, page 537.

Aside: *P*-*V* Diagrams

Example of a *P*-*V* diagram:



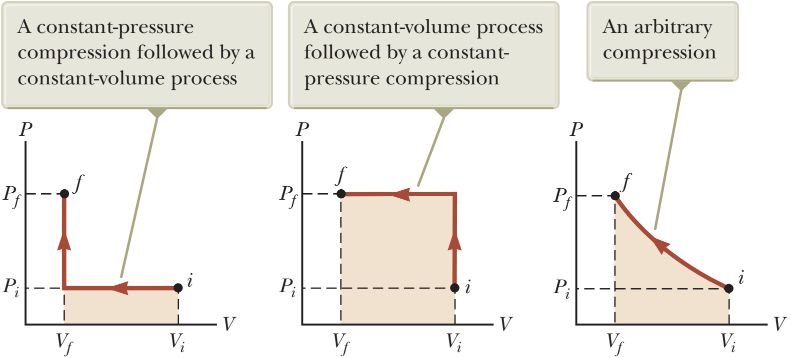
When these diagrams include a path, they

- show reversible processes, eg. compression of gas,
- show all the intermediate thermal states passed through,
- show the work done on the gas,
- indicate the heat transferred to the gas.

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

Work done depends on the process

Different paths or processes to go from (V_i, P_i) to (V_f, P_f) require different amounts of work.



A constant-pressure compression followed by a constant-volume process

A constant-volume process followed by a constant-pressure compression

An arbitrary compression

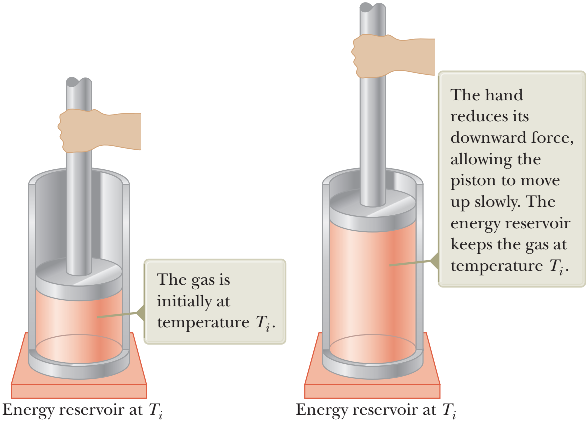
In all of the processes shown above, there are temperature changes during the process.

---

[1] Figure form Serway & Jewett.

Heat transfer also depends on the process

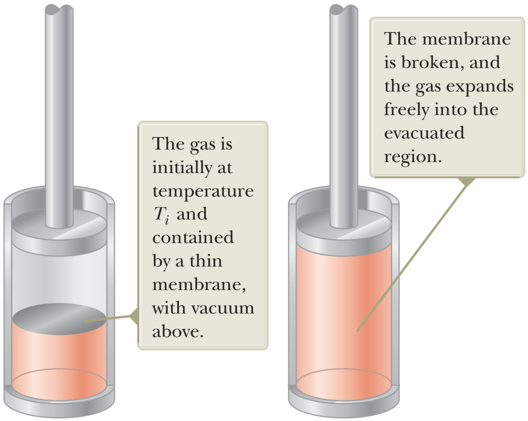
This process (shown) happens at constant temperature:



Heat Q is transferred to the gas, and negative work is done on the gas by the environment.
(Equivalently, the gas does positive work on its surroundings.)

Heat transfer also depends on the process

This process also happens at constant temperature, and has the same start and end points, (V_i, P_i) to (V_f, P_f):



The gas is initially at temperature T_i and contained by a thin membrane, with vacuum above.

The membrane is broken, and the gas expands freely into the evacuated region.

No heat is transferred to the gas, and the gas does no work.

(We cannot represent the path for this process on a P-V diagram.)

Heat transfer also depends on the process

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.

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

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

Summary

- P-V diagrams

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

Homework Serway & Jewett:

- Read chapter 20 and look at the examples.