Thermodynamics
Heat Transfer
Newton's Law of Cooling

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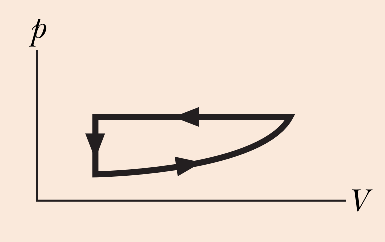
Last time

- work, heat, and the first law of thermodynamics
- P-V diagrams
- applying the first law in various cases

Warm Up Question



For one complete cycle as shown in the P-V diagram here, ΔE_{int} for the gas is

(A) positive

(B) negative

(C) zero

[1] Halliday, Resnick, Walker, page 495.

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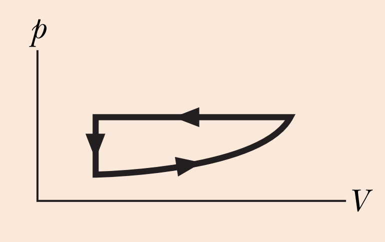

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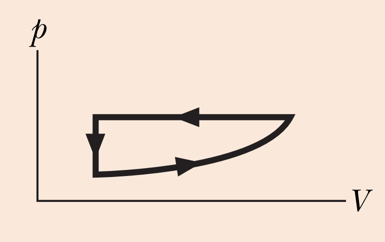

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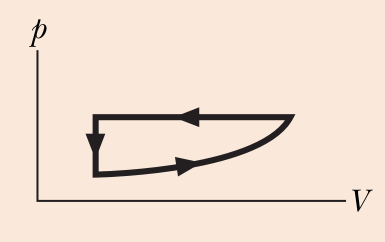

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Overview

- first law and ideal gas example
- heat transfer
- Newton's law of cooling

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

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Work done,

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

Internal energy, ΔE_{int}?

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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,

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

Heat Transfer

We are now changing gears.

We are still thinking about heat in more detail, but we are not necessarily talking about ideal gases.

(Section 20.7 of the textbook.)

Heat Transfer Mechanisms

When objects are in thermal contact, heat is transferred from the hotter object to the cooler object

There are various mechanisms by which this happens:

- conduction
- convection
- radiation

Conduction

Heat can “flow” along a substance.

When it does, heat is said to be transferred by **conduction** from one part of the substance to another.

Some materials allow more heat to flow through them in a shorter time than others.

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Some materials allow more heat to flow through them in a shorter time than others.

These materials are called "good conductors" of heat:

- metals (copper, aluminum, etc)

Conduction

In solids, conduction happens via

- vibrations
- collisions of molecules
- collective wavelike oscillations (phonons)
- diffusion and collisions of free electrons

In liquids and gases, conduction happens through diffusion and collisions of molecules.

Conduction

Some materials are not good conductors and are referred to as **thermal insulators**.

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Examples:

- air (and hence down feathers, wool)
- styrofoam
- wood
- snow

Newton's Law of Cooling (Applies for thermal conduction)

Newton found a relation between the rate that an object cools and its temperature difference from its surroundings.

Objects that are much hotter than their surroundings lose heat much faster than objects that are only a bit hotter than their surroundings.

Using Q for heat:

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = hA\Delta T$$

where A is the heat transfer surface area and h is the heat transfer coefficient

Newton's Law of Cooling (Applies for thermal conduction)

$$\frac{\mathrm{dQ}}{\mathrm{dt}} = hA\,\Delta T$$

If there is no phase change in the substance and the cooling object remains in thermal equilibrium, then we can use the relation for heat capacity:

$$Q = -C\,\Delta T$$

where in this case the heat is transferred out of the hot object to the environment.
to get:

$$\frac{\mathrm{d}(\Delta \mathrm{T})}{\mathrm{dt}} = -r\,\Delta T$$

where the constant $r = hA/C$.

Newton's Law of Cooling Example

Hot leftover soup must be cooled before it can be put in the refrigerator. To speed this process, you put the pot in a sink with cool, running water, that is maintained at 5°C. The hot soup cools from 75°C to 40°C in 8 minutes. Why might you predict that its temperature after another 8 minutes will be 22.5°C?

Summary

- heat transfer
- Newton's law of cooling

Quiz in class Monday, April 30th.

Collected Homework will be posted today, due Monday, May 7th.

Homework Serway & Jewett:

- Read chapter 20 and look at the examples.
- Ch 20, onward from page 615. CQs: 1, 9; (Probs: 43, 45, 47, 51, 55, 84 - can wait to do)