The First Law of Thermodynamics

By:

Utama Alan Deta*

Department of Physics
Faculty of Mathematics and Natural Sciences
Universitas Negeri Surabaya (Unesa)

*)utamadeta@unesa.ac.id
utamaalan@yahoo.co.id

Topics

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*)utamadeta@unesa.ac.id
utamaalan@yahoo.co.id

Work and Heat in Thermodynamic Processes

- In thermodynamics, we describe the state of a system using such variables as pressure, volume, temperature, and internal energy.
- As a result, these quantities belong to a category called state variables.
- A state of a system can be specified only if the system is in thermal equilibrium internally.
- A second category of variables in situations involving energy is transfer variables.
- Such a variable has a nonzero value if a process occurs in which energy is transferred across the system's boundary.

- Consider a gas contained in a cylinder fitted with a movable piston.
- Let's assume we push the piston inward and compress the gas quasi-statically, that is, slowly enough to allow the system to remain essentially in internal thermal equilibrium at all times.
- The work done on the gas is

$$dW = \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}} = -F\hat{\mathbf{j}} \cdot dy\hat{\mathbf{j}} = -F\,dy = -PA\,dy$$

- Or $$dW = -P\,dV$$
- If the gas is compressed, *dV* is negative and the work done on the gas is positive.

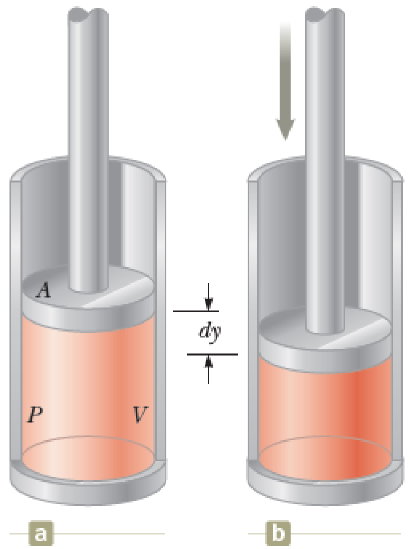

Figure 20.4 Work is done on a gas contained in a cylinder at a pressure P as the piston is pushed downward so that the gas is compressed.

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

- This type of diagram allows us to visualize a process through which a gas is progressing.
- The curve on a PV diagram is called the path taken between the initial and final states.
- The work done on a gas in a quasi-static process that takes the gas from an initial state to a final state is the negative of the area under the curve on a *PV* diagram, evaluated between the initial and final states.

The work done on a gas equals the negative of the area under the *PV* curve. The area is negative here because the volume is decreasing, resulting in positive work.

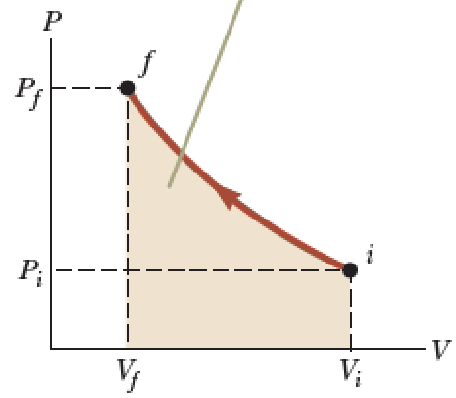

Figure 20.5 A gas is compressed quasi-statically (slowly) from state *i* to state *f*. An outside agent must do positive work on the gas to compress it.

*)utamadeta@unesa.ac.id
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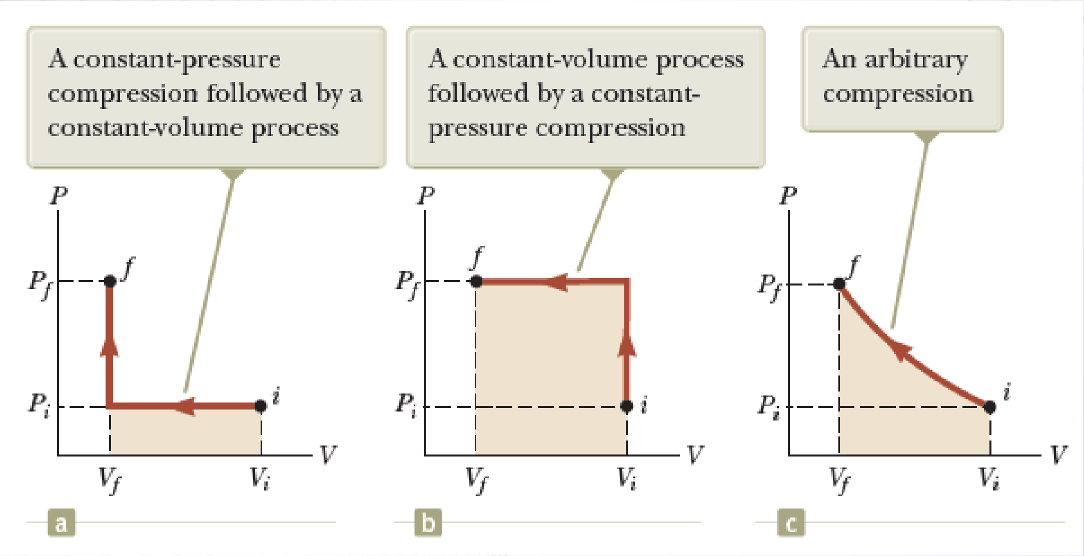

- For the process of compressing a gas in a cylinder, the work done depends on the particular path taken between the initial and final states.

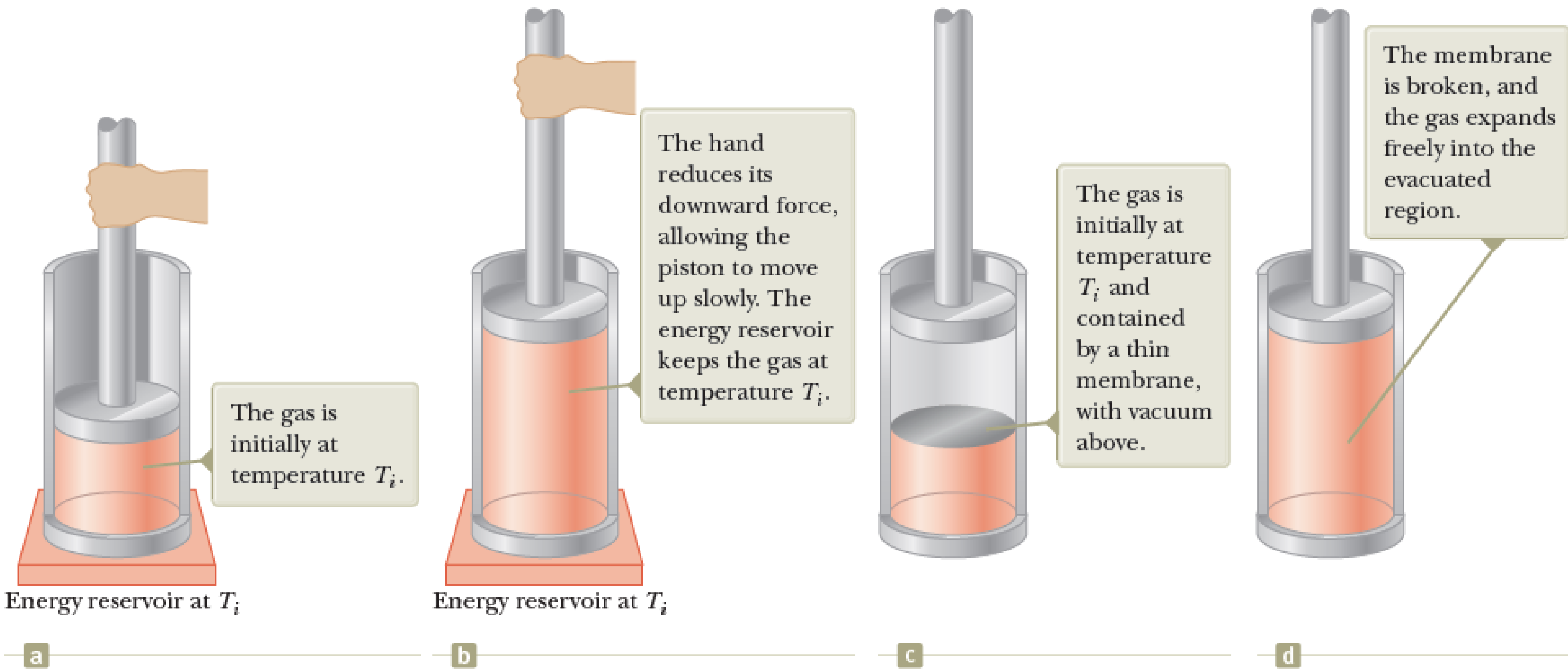

Figure 20.7 Gas in a cylinder. (a) The gas is in contact with an energy reservoir. The walls of the cylinder are perfectly insulating, but the base in contact with the reservoir is conducting. (b) The gas expands slowly to a larger volume. (c) The gas is contained by a membrane in half of a volume, with vacuum in the other half. The entire cylinder is perfectly insulating. (d) The gas expands freely into the larger volume.

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- The energy transfer *Q* into or out of a system by heat also depends on the process.
- In each case, the gas has the same initial volume, temperature, and pressure, and is assumed to be ideal.
- In the first case, the gas does work on the piston and energy is transferred slowly to the gas by heat.
- In the second case, no energy is transferred by heat and the value of the work done is zero.

The First Law of Thermodynamics

- The first law of thermodynamics is a special case of the law of conservation of energy that describes processes in which only the internal energy changes and the only energy transfers are by heat and work:

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

- Isolated system: energy transfer by heat takes place and the work done on the system is zero; hence, the internal energy remains constant.
- Cyclic process: the change in the internal energy must again be zero because E int is a state variable; therefore, the energy *Q* added to the system must equal the negative of the work *W* done on the system during the cycle

$$\Delta E_{int} = 0 \quad \text{and} \quad Q = -W \quad \text{(cyclic process)}$$

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Some Applications of the First Law of Thermodynamics

- Group Discussion
  - Adiabatic Process
  - Isobaric Process
  - Isochoric Process
  - Isotermal Process

*)utamadeta@unesa.ac.id
utamaalan@yahoo.co.id

Energy Transfer Mechanisms in Thermal Processes

- Group Discussion
  - Thermal Conduction
  - Convection
  - Radiation

*)utamadeta@unesa.ac.id
utamaalan@yahoo.co.id