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The First Law of Thermodynamics

Module Overview

Acknowledgments

This presentation is based on and includes content derived from the following OER resource:

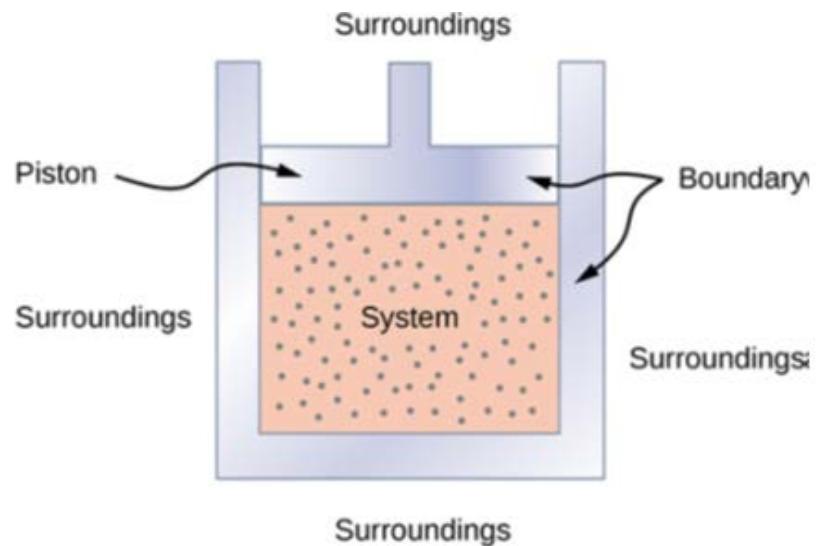
University Physics Volume 2

An OpenStax book used for this course may be downloaded for free at:

<https://openstax.org/details/books/university-physics-volume-2>

Thermodynamic Systems, Part 1

A **thermodynamic system** is anything with thermodynamic properties we wish to study. A system is embedded in an **environment** or **surroundings** and can interact with it through a **boundary**. A system is called a **closed system** if it is completely isolated from its environment, and it is called an **open system** if it can interact with its environment.



(University Physics Volume 2. OpenStax. Fig. 3.2.)

Thermodynamic Systems, Part 2

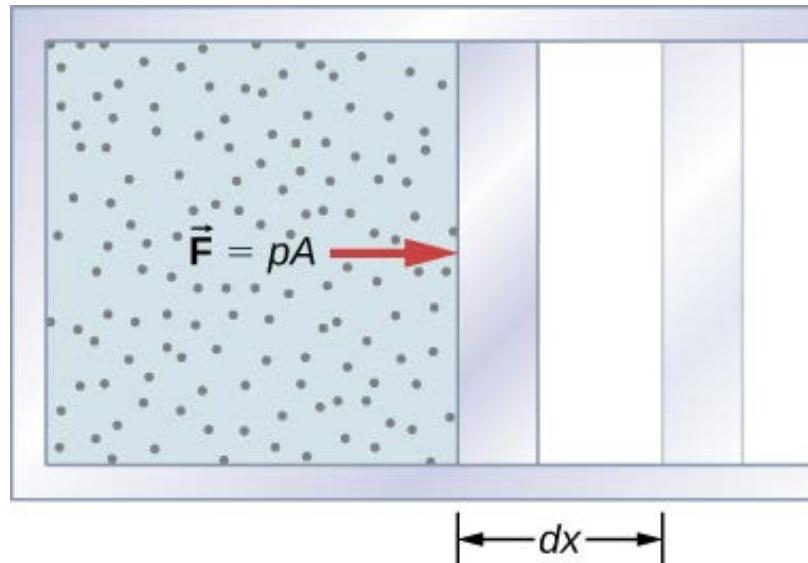
When studying a system, we examine its macroscopic properties, ignoring the details of its constituents, and we assume it is in **equilibrium**, meaning the thermodynamic properties are identical throughout the system. The zeroth law of thermodynamics states that if $T_1 = T_2$ and $T_1 = T_3$, then $T_2 = T_3$.

The **equation of state** of a closed thermodynamic system relates the macroscopic variables that describe a system. For many systems, the equation of state is described symbolically as a function f , such that $f(p, T, V) = 0$.

An **extensive variable** is one that depends on the amount of a substance. An **intensive variable** is independent of the amount of a substance.

Work Done by a System, Part 1

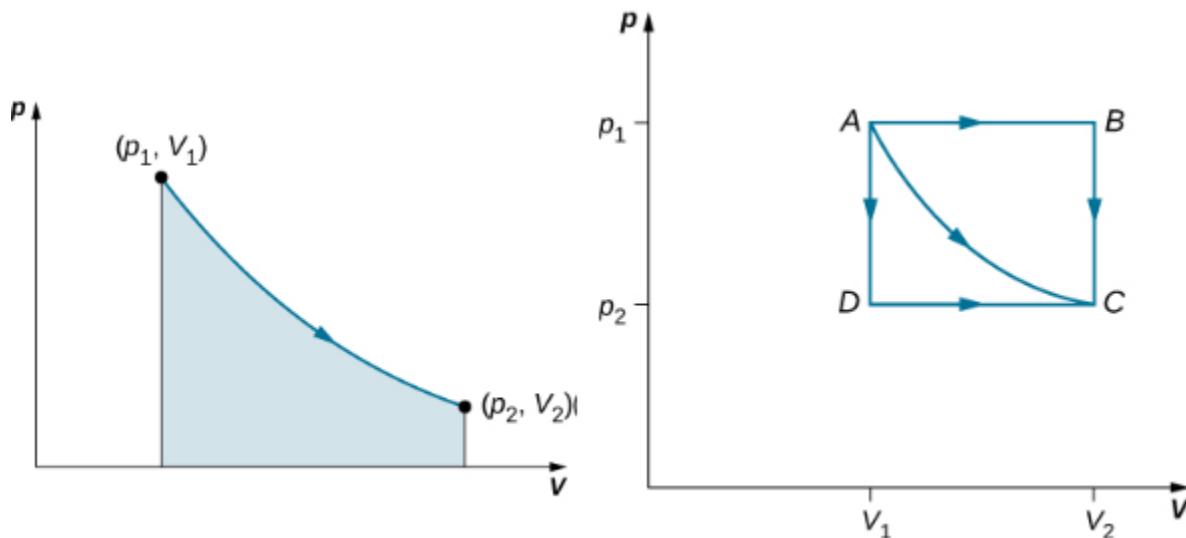
A thermodynamic system may do work by applying a pressure p as it expands by a volume dV . The net work done by a system as it expands from V_1 to V_2 is defined by the integral $W = \int_{V_1}^{V_2} pdV$. This integral applies to **quasi-static** processes, which are processes that take place in infinitesimal steps, maintaining thermal equilibrium at each step.



(University Physics Volume 2. OpenStax. Fig. 3.4.)

Work Done by a System, Part 2

The work done by a system is equal to the area under a pV graph showing the change in its state. From a pV graph showing two different paths from two states, it is clear that the work done by a system is dependent on the path taken between the initial and final states.



(University Physics Volume 2. OpenStax. Figs. 3.5, 3.6.)

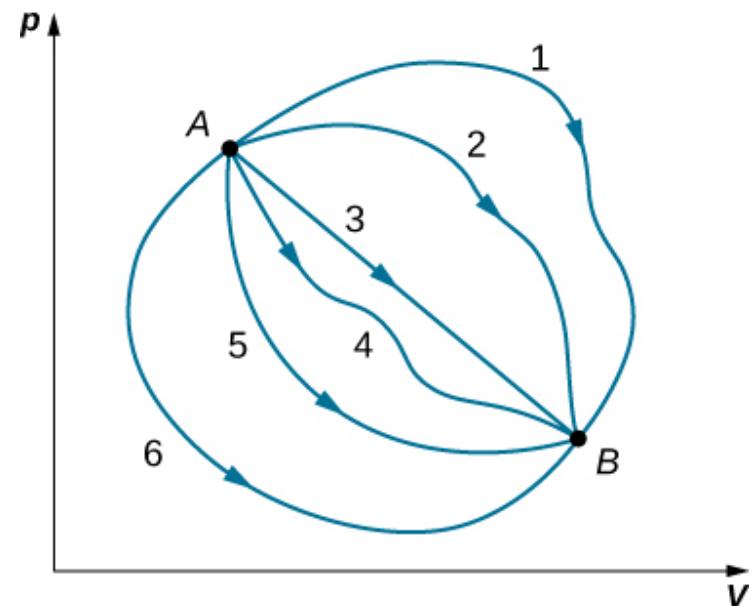
Internal Energy

The **internal energy** E_{int} of a thermodynamic system is the sum of the mechanical energies of the constituents of the system, $E_{\text{int}} = \sum_i (\bar{K}_i + \bar{U}_i)$. In an ideal monatomic gas, there is only translational kinetic energy, and the potential is a constant that we choose to be zero. The resulting internal energy is $E_{\text{int}} = \sum_i \bar{K}_i = \sum_i \frac{1}{2} m_i \bar{v}_i^2$. We know that the average kinetic energy of a molecule in an ideal monatomic gas is given by $\frac{1}{2} m_i \bar{v}_i^2 = \frac{3}{2} k_B T$. Thus, the total internal energy of an ideal gas is just the molecular energy times the number of atoms, $E_{\text{int}} = n N_A \frac{3}{2} k_B T = \frac{3}{2} n R T$.

First Law of Thermodynamics

The **first law of thermodynamics** states that the change in internal energy of a system is given by the difference in the heat Q added to it and the work W done by it, $\Delta E_{\text{int}} = Q - W$.

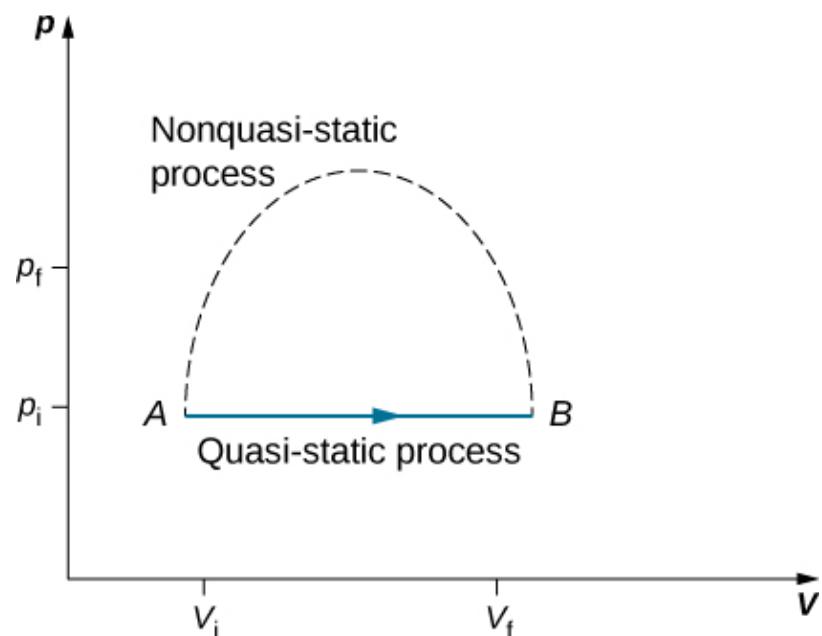
This is a statement of conservation of energy for thermodynamic systems. Though the heat transfer and work done by a system are path dependent, the internal energy is a state variable, meaning it is path independent.



(University Physics Volume 2. OpenStax. Fig. 3.7.)

Quasi-Static and Non-Quasi-Static Processes

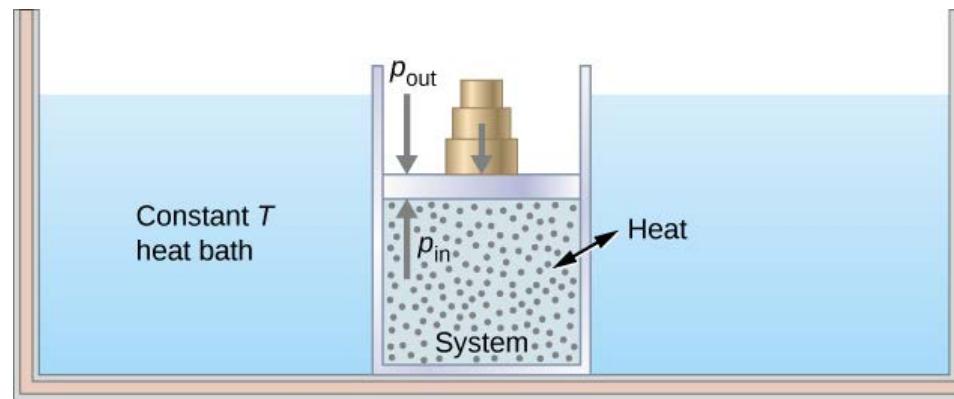
A **thermodynamic process** is the manner in which a system changes from an initial to a final state. A quasi-static process is an idealized process where the change in state is so slow that the system is at thermodynamic equilibrium at every instant. All real processes are non-quasi-static, but we can often make the quasi-static assumption to make a problem tractable.



(University Physics Volume 2. OpenStax. Fig. 3.8.)

Isothermal Processes

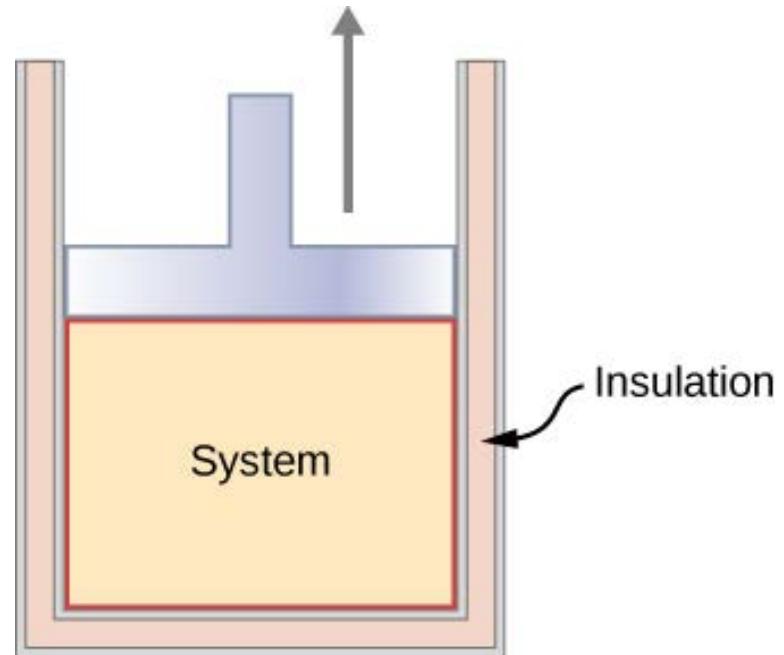
An **isothermal process** is a change in state that occurs at constant temperature, usually accomplished by immersing a system in a heat bath. For an ideal gas, the pressure and volume change inversely to maintain the temperature, $p \propto \frac{1}{V}$. Other quasi-static processes include the **isobaric process**, where pressure is held constant, and the **isochoric process**, where volume is held constant.



(University Physics Volume 2. OpenStax. Fig. 3.9.)

Adiabatic Processes

An **adiabatic process** is completely insulated from its environment, meaning no heat is allowed to enter or leave the system. In order to expand adiabatically, a system must do work on the environment. This causes a lowering of the system's internal energy and temperature. Conversely, adiabatic compression increases a system's internal energy and temperature.



(University Physics Volume 2. OpenStax. Fig. 3.11.)

Cyclic Processes

A **cyclic process** is one where the system starts and ends at the same state. As a result, the internal energy does not change, $\Delta E_{\text{int}} = 0$, and the heat added to the system is equal to the work done by the system as a result of the first law of thermodynamics, $Q = W$.

A **reversible process** is a quasi-static process that can be returned to its original state by the same path traced in reverse. A quasi-static process is not necessarily reversible, since dissipative forces like friction or drag may be involved.

Heat Capacities of an Ideal Gas

Consider a gas with fixed walls that undergoes a change in temperature dT . Since the gas cannot do work, the change in internal energy is $dE_{\text{int}} = dQ$. The relationship between the heat-added dQ and the change in temperature of the gas is $dQ = C_V dT$, where C_V is the **molar heat capacity at constant volume**.

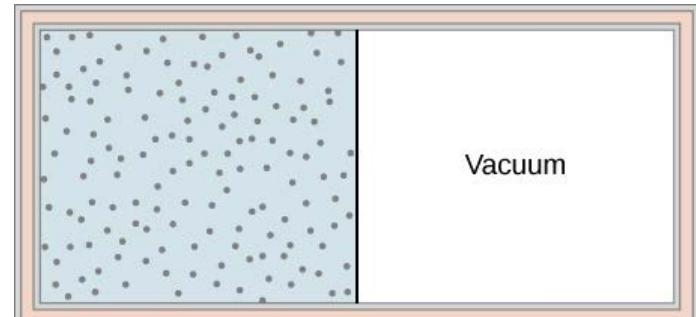
Consider next a gas with a freely moving piston that expands and does work $dW = pdV$. In this case, the process occurs at constant pressure and the relationship between heat and temperature is $dQ = C_p dT$, where C_p is the **molar heat capacity at constant pressure**.

The two quantities are related to the universal gas constant by $C_p = C_V + R$.

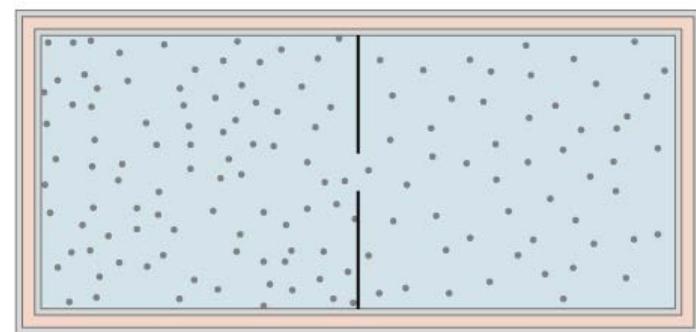
Adiabatic Processes for an Ideal Gas

For free expansion into a vacuum, a gas does no work and is at constant volume.

From the first law of thermodynamics and the ideal gas law, we find a relationship between the pressure and volume during adiabatic processes, $pV^\gamma = \text{constant}$, where $\gamma = \frac{C_p}{C_V}$. The slope of an adiabatic curve on a pV diagram is $\frac{dp}{dV} = -\frac{p}{V}$.



Initial equilibrium state

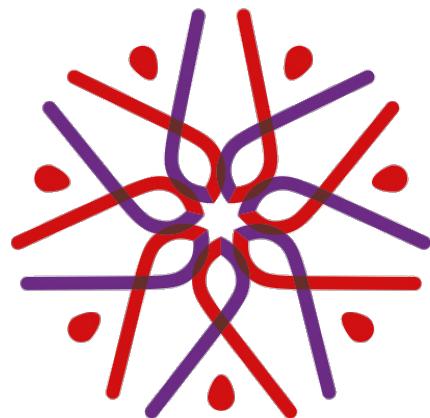


Final equilibrium state

(University Physics Volume 2. OpenStax. Fig. 3.13.)

How to Study this Module

- Read the syllabus or schedule of assignments regularly.
- Understand key terms; look up and define all unfamiliar words and terms.
- Take notes on your readings, assigned media, and lectures.
- As appropriate, work all questions and/or problems assigned and as many additional questions and/or problems as possible.
- Discuss topics with classmates.
- Frequently review your notes. Make flow charts and outlines from your notes to help you study for assessments.
- Complete all course assessments.



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