ESO 201A: Thermodynamics

2016-2017-I semester

Energy Analysis of Closed Systems: part 1

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Learning objective

- Examine the moving boundary work or $P\,dV$ work commonly encountered in reciprocating devices such as automotive engines and compressors.
- Identify the first law of thermodynamics as simply a statement of the conservation of energy principle for closed (fixed mass) systems.
- Develop the general energy balance applied to closed systems.
- Define the specific heat at constant volume and the specific heat at constant pressure.
- Relate the specific heats to the calculation of the changes in internal energy and enthalpy of ideal gases.
- Describe incompressible substances and determine the changes in their internal energy and enthalpy.
- Solve energy balance problems for closed (fixed mass) systems that involve heat and work interactions for general pure substances, ideal gases, and incompressible substances.

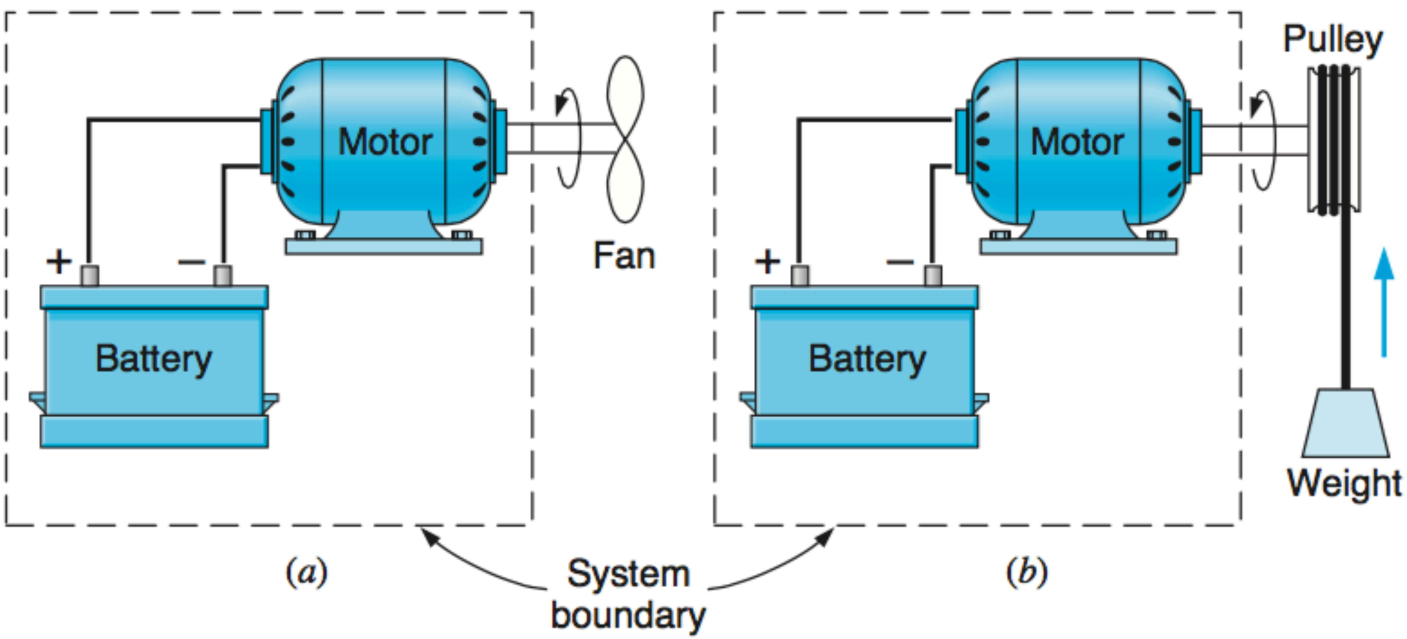
Work

Work is usually defined as a force F acting through a displacement x where the displacement is in the direction of the force.

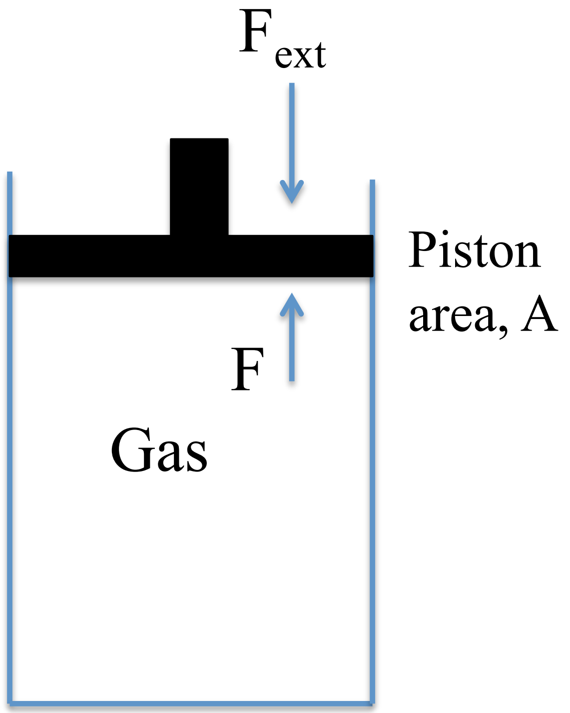
$$W = \int_1^2 F\,dx$$

Work is done by a system if the sole effect on the surroundings (everything external to the system) could be the raising of a weight.

Work is a form of energy in transit, recognized at the boundary.



Work



Our interest is in the, F_{ext}, force required on our part, by the surrounding, to compress the gas to lets say half of its volume?

Or force felt by the surrounding as the gas expands ?

The general differential definition of mechanical work

$$\delta W = F_{ext} dl = \left(\frac{F_{ext}}{A}\right) A dl = P_{ext} dV$$

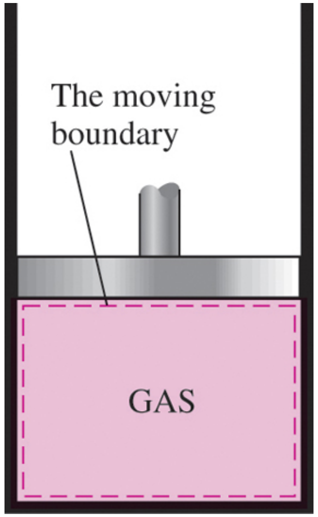
P_{ext} need not be equal to P_{int}=P=F/A

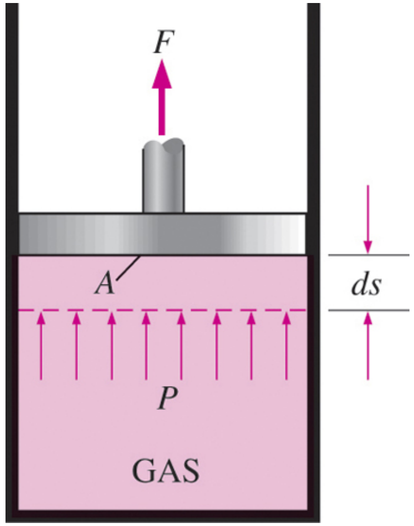
Limiting case: P_{ext} and P_{int} are nearly equal, but one is infinitesimally larger to accomplish a net change in volume: quasi-static equilibrium

Only for such case P=P_{ext} and $\delta W = PdV$

The moving boundary work

The work associated with a moving boundary is called *boundary work.*





A gas does a differential amount of work W_b as it forces the piston to move by a differential amount *ds*.

Moving boundary work (*P dV* work): The expansion and compression work in a piston-cylinder device.

$$\delta W_b = F\,ds = PA\,ds = P\,dV$$

$$W_b = \int_1^2 P\,dV \qquad (\text{kJ})$$

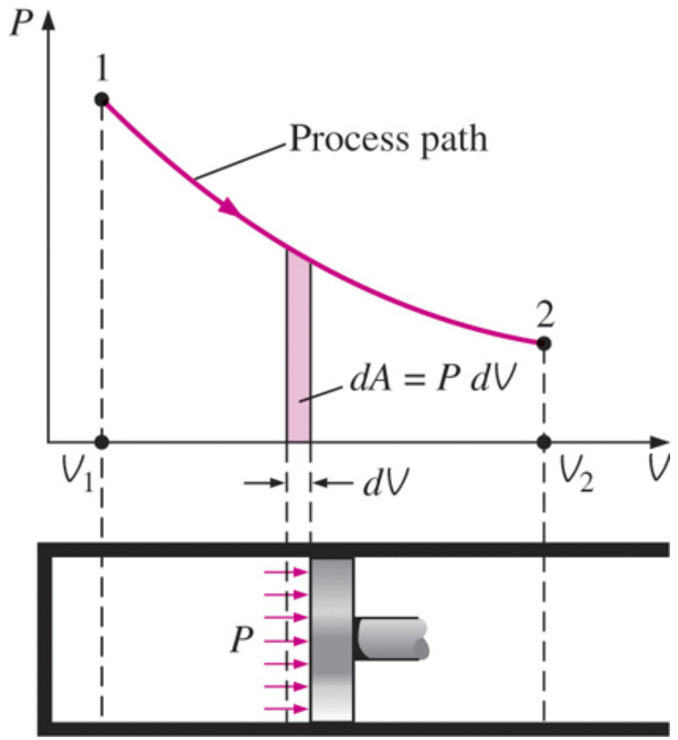
W_b is positive for expansion
W_b is negative for compression

The moving boundary work

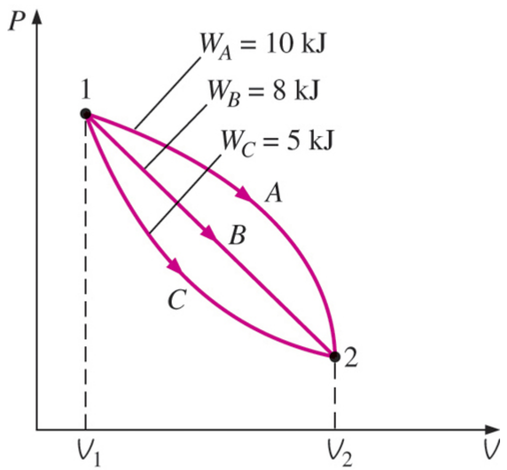
Quasi-equilibrium process: A process during which the system remains nearly in equilibrium at all times.

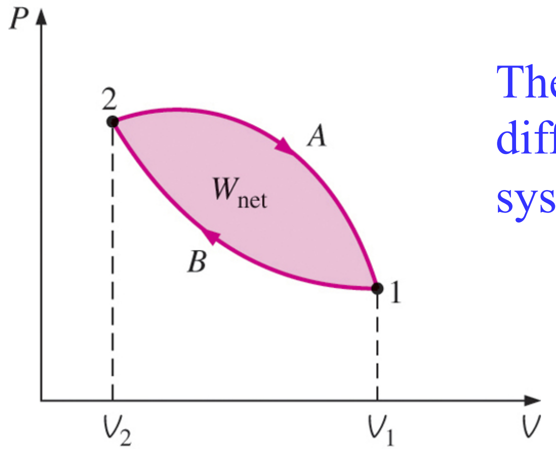
The area under the process curve on a P-V diagram represents the boundary work.

$$\text{Area} = A = \int_1^2 dA = \int_1^2 P\, dV$$



The boundary work done during a process depends on the path followed as well as the end states.



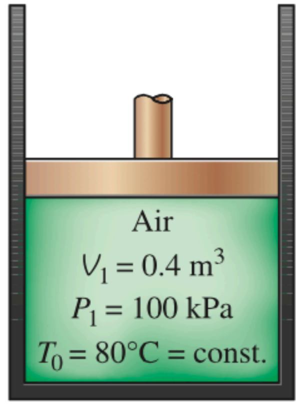


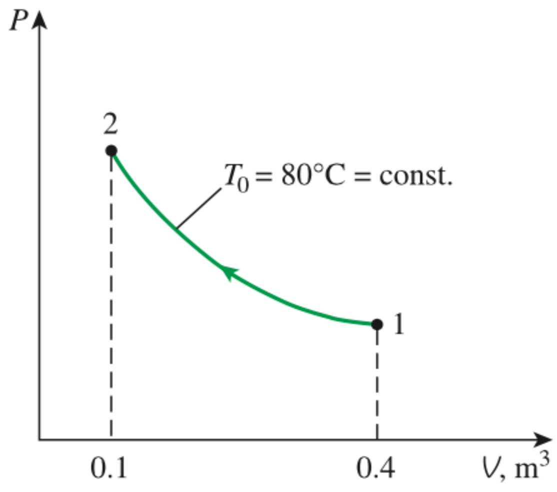
The net work done during a cycle is the difference between the work done by the system and the work done on the system.

Example

A piston–cylinder device initially contains 0.4 m^3 of air at 100 kPa and 80°C. The air is now compressed to 0.1 m^3 in such a way that the temperature inside the cylinder remains constant. Determine the work done during this process

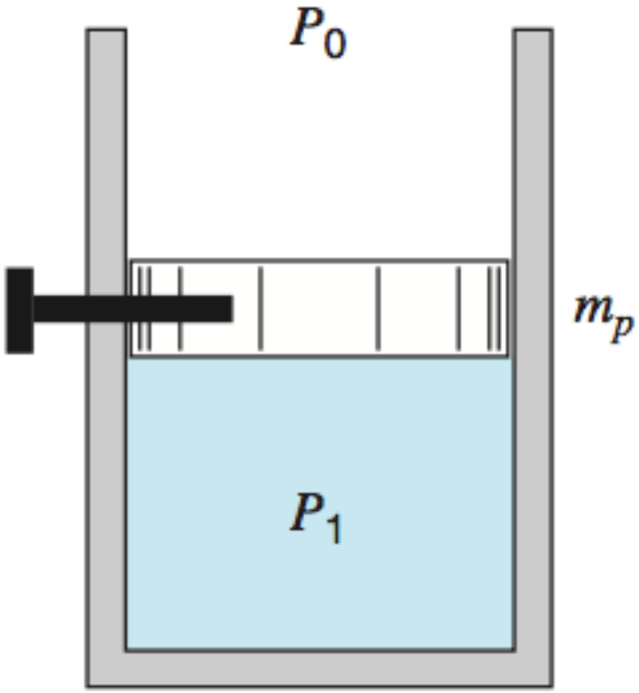
- Quasi-equilibrium process
- Air is an ideal gas





The moving boundary work

Consider the system in which the piston of mass m_p is initially held in place by a pin. The gas inside the cylinder is initially at pressure P_1 and volume V_1. When the pin is released, calculate the work done by the system when the piston has come to rest.



Next lecture

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