II. Energy and the First Law of Thermodynamics

A. Energy Transfer by Work. Energy is Conserved.

1. Energy can cross the boundary of a closed system by only two mechanisms: heat transfer and work transfer.
2. The change in energy of a closed system is equal to the net heat transferred to the system minus the net work performed by the system.

Net work out, $W_{out,net} = W_{out} - W_{in}$

$$\boxed{\Delta E_{total} = \Delta E_{system} + \Delta E_{surroundings} = 0}$$

$$\boxed{\Delta E_{system} = -\Delta E_{surroundings}}$$

Closed system

$$\boxed{\Delta E_{sys} = Q_{in,net} - W_{out,net}}$$

(2-34), p. 73; (4-17), p 174

Net heat in, $Q_{in,net} = Q_{in} - Q_{out}$

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B. Mechanical work and power

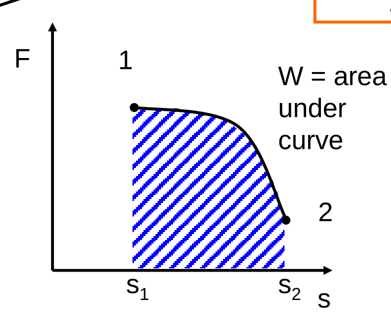
1. Introduction

a. Work done by force F on a body displaced distance s is

Constant force $\boxed{W = Fs\ (kJ)}$

$\boxed{W = \int_1^2 F\,ds\ (kJ)}$ Variable force

(2-22)



b. Power supplied to body moving with velocity V: $\boxed{\dot{W} = FV\ (kW)}$

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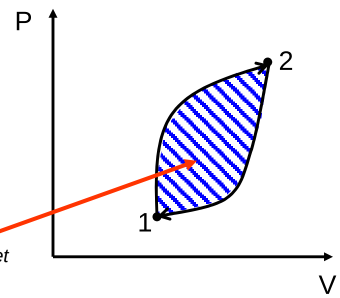
c. Work and heat are processes, not properties. Work and heat are represented as areas on a graph. E, e, V, T, P, m are properties and are represented by points on a graph.

d. Work and heat are also known as path functions.

$$\int_1^2 dE = E_2 - E_1 = \Delta E$$ (any path between states 1, 2)

$$\oint dE = 0 \ \text{ or } \ \oint dV = 0$$ (any cycle)

$$\int_1^2 \delta W = W_{12}$$ (not ΔW)



Shaded area = $\oint \delta W_{out} = W_{out,net}$

lesson 4

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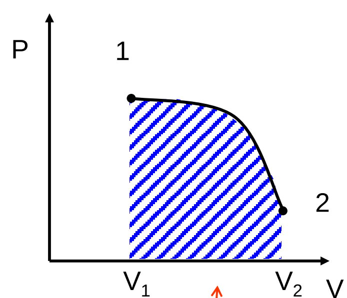
2. Expansion and compression work
   a. Transfer of energy to a system by boundary work requires that a force act on the boundary and that the boundary move
   b. Differential work done by the system is, for a piston of area A,

$$\boxed{\delta W_{b,out} = F\,ds = PA\,ds = P\,dV}$$

   c. Replacing F with pA is strictly correct only for a quasi-equilibrium (reversible) process
   d. The total boundary work done by system is area under curve P = f(V)

$$\boxed{W_{b,out} = \int_{V_1}^{V_2} P\,dV} \quad (4\text{-}2)$$



lesson 4

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3. Evaluation of integral

(4-2) $$\boxed{W_{b,out} = \int_{V_1}^{V_2} P\,dV}$$

Remember that this equation only applies to a quasi-equilibrium (reversible) process.

How can we evaluate this integral? We look at three examples:

- P may be constant (see Example 4-2, p. 169).
- P may be defined by ideal gas law for an isothermal process (see Example 4-3, p. 170).
- Process may be polytropic (see p. 171).

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3. Evaluation of integral. Example - Air is contained in a piston-cylinder device at 500 kPa at an initial volume of 0.040 m^3. The air expands to a final volume of 0.075 m^3. Calculate the work output under conditions of (a) constant pressure, (b) constant temperature.

<u>Data</u>
$V_1 = 0.040\ m^3$
$V_2 = 0.075\ m^3$
$P_1 = 500\ kPa$

<u>Model</u>
1) Closed system.
2) Quasi-equilibrium process.
3) Ideal gas: PV = mRT

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3. Example (cont.)

(a) Analysis (constant pressure)

$$W_{out} = \int_{V_1}^{V_2} PdV = P(V_2 - V_1)$$

$$W_{out} = 500\ kPa(0.075 - 0.040)\ m^3 = 18\ kJ$$

(b) Analysis (constant temperature)

$$W_{out} = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{mRT}{V} dV = mRT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$W_{out} = mRT \ln\left(\frac{V_2}{V_1}\right) = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$W_{out} = 500\ kPa(0.04\ m^3)\ln\left(\frac{75}{40}\right) = 13\ kJ$$

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4. Polytropic process (p. 171 of text)

Many compression and expansion processes can be modeled as polytropic processes. The boundary work for such a process can be calculated as follows, where n is typically 1.2 or 1.3.

$$PV^n = C \text{ or } P = CV^{-n}$$

$$W_{out} = \int_{V_1}^{V_2} PdV$$

n = 0 and n = 1 correspond to isothermal and constant pressure cases considered above.

$$W_{out} = C\int_{V_1}^{V_2} V^{-n} dV = C \left.\frac{V^{1-n}}{1-n}\right|_{V_1}^{V_2} = \frac{P_2V_2 - P_1V_1}{1-n},\ n \neq 1 \qquad (4\text{-}9)$$

For an ideal gas, PV = mRT and

$$W_{b,out} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n},\ n \neq 1 \qquad (4\text{-}10)$$