



UTM
UNIVERSITI TEKNOLOGI MALAYSIA

OPENCOURSEWARE

Thermodynamics I

Chapter 3

Energy, Heat and Work

Mohsin Mohd Sies

Fakulti Kejuruteraan Mekanikal, Universiti Teknologi Malaysia



Energy, Heat and Work (Motivation)

A system changes due to interaction with its surroundings.

Energy interaction is a major factor.

This chapter studies the nature of energy and its various forms and transfers so that we are able to follow its interaction with a system.

ENERGY & THE 1st LAW OF THERMO.

1st Law : concerning quantity of energy

Energy is conserved

(Amount of energy is constant, but can change forms)

(e.g. potential, kinetic, electrical, chemical, etc.)

$$E = \text{Total system energy [J, kJ]}$$

$$e = \frac{E}{m} \left[\frac{\text{kJ}}{\text{kg}} \right] (\text{specific energy})$$



Energy

Macroscopic – system energy which value depends on a *reference point* (Kinetic Energy (KE), Potential Energy (PE))

Microscopic – energy due to *molecular interactions & activity* (independent of any reference point) (Internal Energy, U)

Total System Energy

$$E = KE + PE + U \text{ [kJ]}$$

$$e = ke + pe + u \text{ [kJ/kg]}$$





Kinetic Energy (KE)

$$\begin{aligned} \text{KE} &= \frac{m\vec{V}^2}{2} & \Delta\text{KE} &= \frac{m}{2} [\vec{V}_2^2 - \vec{V}_1^2] \\ \text{ke} &= \frac{\text{KE}}{m} = \frac{\vec{V}^2}{2} & \Delta\text{ke} &= \frac{\Delta\text{KE}}{m} = \frac{(\vec{V}_2^2 - \vec{V}_1^2)}{2} \end{aligned}$$

Potential Energy (PE)

$$\begin{aligned} \text{PE} &= mgz & \Delta\text{PE} &= mg(z_2 - z_1) \\ \text{pe} &= \frac{\text{PE}}{m} = gz & \Delta\text{pe} &= \frac{\Delta\text{PE}}{m} = g(z_2 - z_1) \end{aligned}$$



Internal Energy, U

— Molecular movement (vibration, collision, etc)
sensible energy (molecular activity
temperature)

— Bond Energy between molecules (phase
change)
latent energy (constant temperature)

— Bond Energy between atoms in a molecule
chemical energy

— Bond Energy between protons & neutrons in
the nucleus
nuclear energy

Modes of Energy Transfer

Energy Interaction between
System and Surrounding

Energy can cross the boundary (transferred)
of a closed system by **2 methods**;

HEAT & WORK

HEAT, Q [J, kJ]

Heat - Energy that is *being transferred* due to a temperature difference

- Heat is a mode of energy transfer
- Heat is not a property
- Energy is related to states (property)
- Heat is related to processes (not a property, depends on the path)

$$q = \frac{Q}{m}$$

$$\dot{Q} = \frac{Q}{t} \left[\frac{\text{kJ}}{\text{s}} = \text{kW} \right]$$

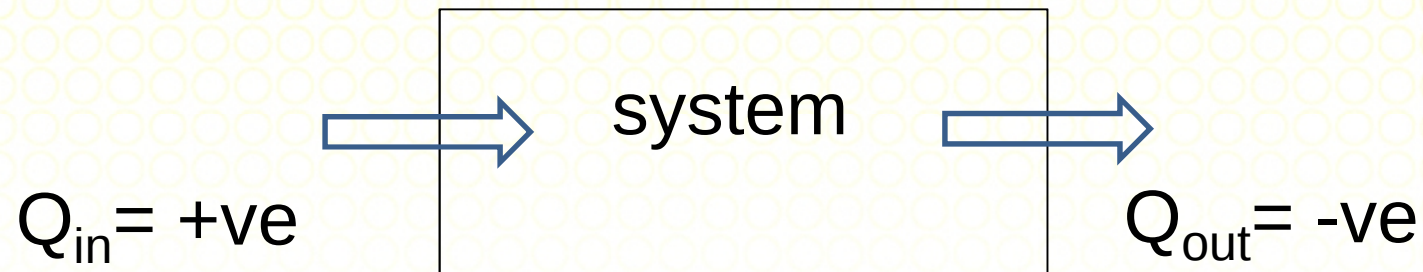
= rate of heat transfer

$$\int_1^2 \delta Q = Q_{12}$$

Amount of heat transferred during a process (depends on the path)



Heat (ctd.)



Adiabatic Process ($Q = 0$)

insulated
 $T_{system} = T_{surrounding}$

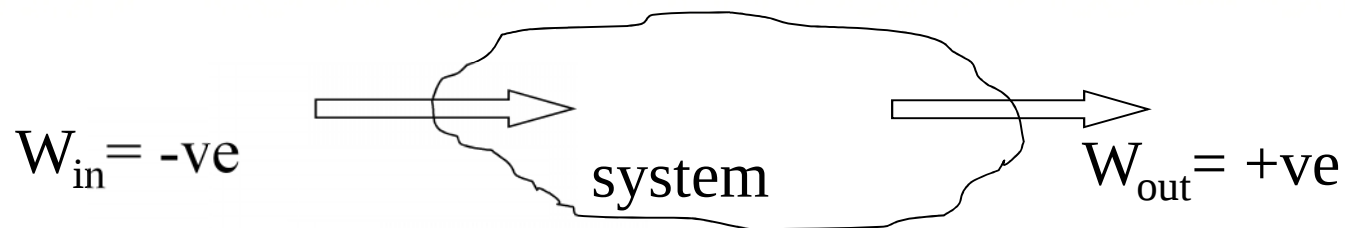
Adiabatic $\neq$ Isothermal!

(T can change by other methods;
energy can enter system by work)

WORK, W [J, kJ]

Work --Energy that is *crossing the boundary* other than heat
 (electrical, stirrer, shaft, moving piston, etc.)

- Not a property (related to *process*)
- Mode of energy *transfer*



$$w = \frac{W}{m} \left[\frac{kJ}{kg} \right]$$

$$\dot{W} [kW] = \frac{W}{t} \left[\frac{kJ}{s} \right] = \text{rate of work} = \text{power}$$

$$\int_1^2 \delta W = W_{12} \leftarrow \text{Depends on path}$$



Types of Work

Work

Electrical

$$W_{el} = \int_1^2 V I dt$$

Mechanical

$$W = \int_1^2 \mathbf{F} \cdot d\mathbf{s}$$

Boundary

$$W_b = \int_1^2 p \cdot dV$$

Gravitational

$$W_g = mg (z_2 - z_1)$$

Acceleration

$$W = \frac{1}{2} m (\vec{V}_2^2 - \vec{V}_1^2)$$

Shaft

$$W = 2 \pi n \tau$$

Spring

$$W = \frac{1}{2} k (x_2^2 - x_1^2)$$

Boundary Work for Polytropic Processes

Boundary Work

$$W_B = \int_{V_1}^{V_2} P dV$$

Area under P-v graph

General Polytropic Work

$$W = \frac{P_2 V_2 - P_1 V_1}{1 - n} \quad (n \neq 1)$$

Const. Pressure Work (n=0)

$$W = p (V_2 - V_1)$$

Isothermal Work (n=1) *ideal gas*

$$W = mRT \ln \left(\frac{V_2}{V_1} \right) = mRT \ln \left(\frac{P_1}{P_2} \right)$$

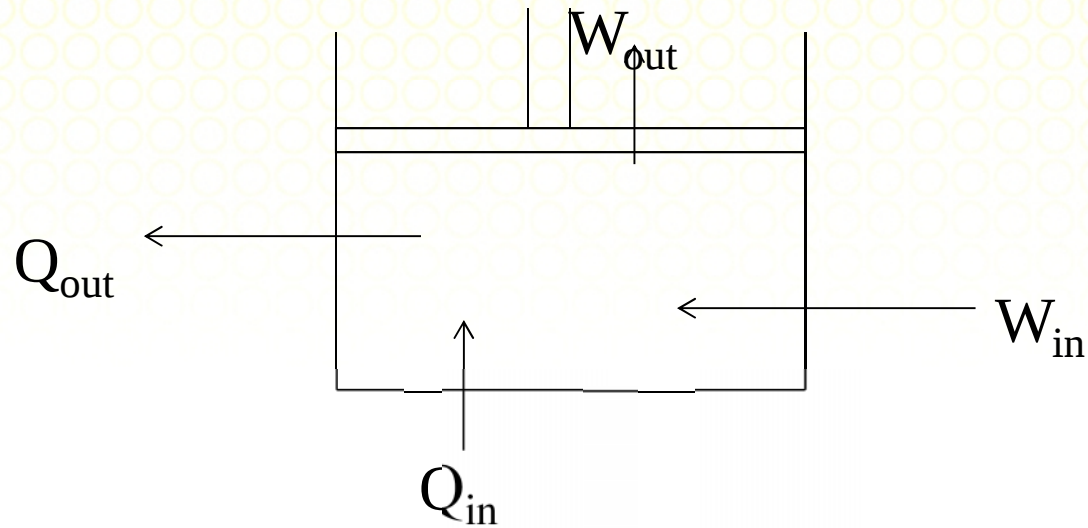
Const. Volume Work (dv=0)

$$W_{b-constvol} = 0$$





1st Law Closed System



$$\Delta E = \underbrace{\sum Q - \sum W}$$

Net change of system
energy

Net total energy transfer in the
form of heat and work





- Recall that System Energy consists of:

$$E_{\text{system}} = U + KE + PE$$

or

$$\Delta E_{\text{system}} = \Delta U + \Delta KE + \Delta PE$$

thus;

$$Q - W = \Delta E_{\text{system}} = \Delta U + \Delta KE + \Delta PE$$

Or can be called as the

1st Law/Energy Balance of a Closed System;

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

Net *transfer* of energy

Energy *storage* in different modes



1st Law for Closed System in different forms;

$$Q - W = \Delta U + \Delta KE + \Delta PE \quad [\text{kJ}]$$

per unit mass;

$$q - w = \Delta u + \Delta ke + \Delta pe \quad [\text{kJ/kg}]$$

Rate form;

$$\dot{Q} - \dot{W} = \frac{dU}{dt} + \frac{d(KE)}{dt} + \frac{d(PE)}{dt} \quad [\text{kW}]$$

Cyclic Process $\Delta E = 0$

$$Q - W = 0$$

$$Q_{\text{cycle}} = W_{\text{cycle}}$$

$$\sum Q = \sum W$$

summary:

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

$$mg(z_2 - z_1)$$

$$\frac{m (V_2^2 - V_1^2)}{2}$$

$$m(u_2 - u_1) \quad \text{water (Table)}$$

$$mC_v(T_2 - T_1) \quad \text{ideal gas}$$

$$\text{Electrical} \quad W_{el} = \int_1^2 VI dt$$

$$\text{Mechanical} \quad W = \int_1^2 F \cdot ds$$

$$\text{Boundary} \quad W_b = \int_1^2 p \cdot dV$$

etc...

