Thermodynamics
ENGR360-MEP112

LECTURE 3

ENERGY, ENERGY TRANSFER, AND ENERGY ANALYSIS

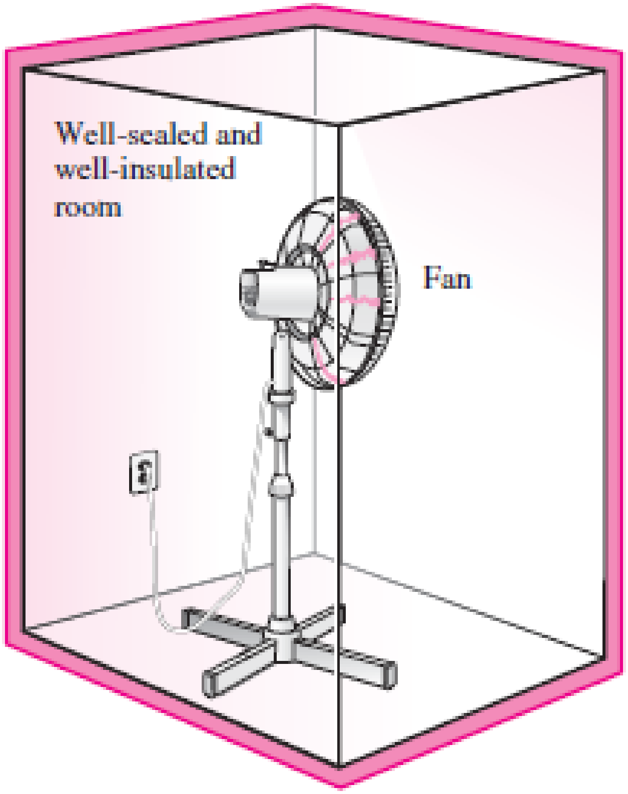
Objectives:

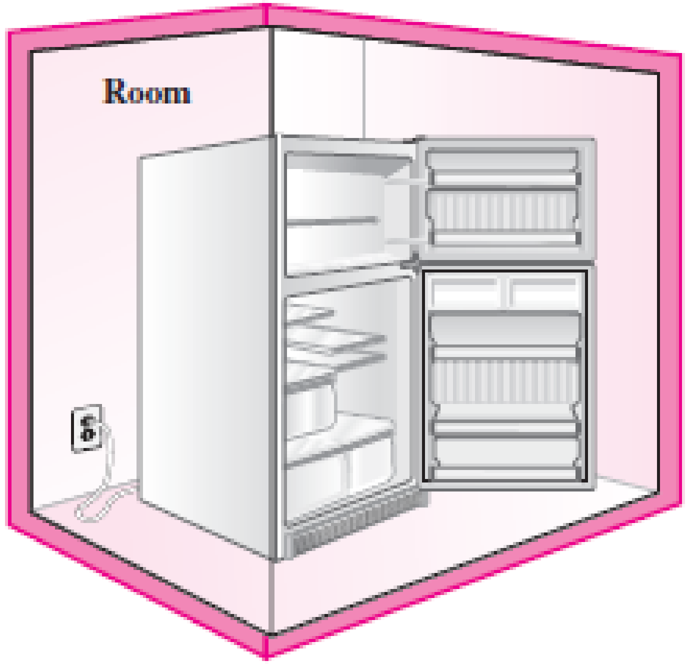
1. Introduce the concept of energy and define its various forms.
2. Discuss the nature of internal energy.
3. Define the concept of heat and work and the terminology associated with each.

1. CONCEPT OF ENERGY

- **The conservation of energy principle is an expression of the first law of thermodynamics.**

Energy cannot be created or destroyed during a process; it can only change from one form to another





A running fan and refrigerator operating with its door open in a well-sealed and well-insulated room.

1. CONCEPT OF ENERGY

- **Electricity is of the highest quality of energy. It can always be converted to an equal amount of thermal energy (also called heat). But only a small fraction of heat, which is the lowest quality of energy, can be converted back to electricity.**

2. FORMS OF ENERGY

- **Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the total energy E of a system. The total energy of a system on a unit mass basis is denoted by e and is expressed as:**

$$e = \frac{E\ (\text{Joule})}{m\ (\text{kilogram})}\ \ (\text{J/kg})$$

- **Thermodynamics deals with the change of the total energy (ΔE), which is what matters in engineering problems. Thus the total energy of a system can be assigned a value of zero (E = 0) at some convenient reference point. The change in total energy (ΔE) of a system is independent of the reference point selected.**

2. FORMS OF ENERGY

- **The decrease in the potential energy of a falling rock, for example, depends on only the elevation difference and not the reference level selected.**

- **The macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame such as kinetic and potential energies.**

The macroscopic energy of an object changes with velocity and elevation.

2. FORMS OF ENERGY

- The **microscopic forms of energy** are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames.

- The **sum** of all the **microscopic forms of energy** is called the **internal energy** of a system and is denoted by **U**.

$$U = \sum \text{Microscopic energy}$$

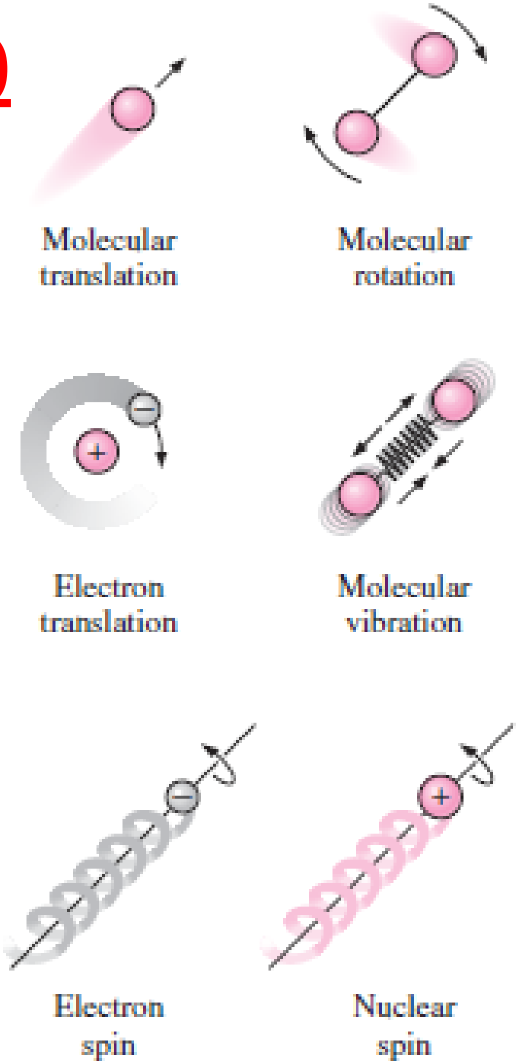
$$u = \frac{U}{m} \; (\text{J/kg})$$

Physical Insight to Internal Energy (U)

- **Sensible energy**: is the portion of the internal energy of a system associated with the kinetic energies of the molecules.

- **Latent energy**: is the portion of the internal energy of a system associated with the phase change of a system.

- **Chemical energy**: is the portion of the internal energy of a system associated with the atomic bonds in a molecule.



The various forms of microscopic energies that make up *sensible* energy.

2. FORMS OF ENERGY

- **Kinetic energy (KE): is the energy that a system possesses as a result of its motion relative to some reference frame.**

$$KE = m\frac{v^2}{2}\ (J) \quad \& \quad ke = \frac{v^2}{2}\ (J/kg)$$

Velocity

- **Potential energy (KE): is the energy that a system possesses as a result of its elevation in a gravitational field.**

$$PE = mgz\ (J) \quad \& \quad pe = gz\ (J/kg)$$

Extensive

Intensive

2. FORMS OF ENERGY

- The total energy (E) of a system consists of the kinetic, potential, and internal energies and is expressed as:

$$\mathbf{E = Microscopic\ part + Macroscopic\ part}$$

$$\mathbf{E = U + KE + PE = U + m\frac{v^2}{2} + mgz \quad (J)}$$

or, on a unit mass basis

$$\mathbf{e = u + ke + pe = u + \frac{v^2}{2} + gz \quad (J/kg)}$$

Mass flow rate and energy flow rate

- **Closed systems** whose velocity and elevation of the center of gravity remain constant during a process are frequently referred to as **stationary systems**.

- **Control volumes** typically involve fluid flow. It is convenient to express the **energy flow** associated with a fluid stream in the **rate form**. This is done by incorporating the mass flow rate **($\dot{m}$)**.

- The **mass flow rate ($\dot{m}$)**: is the amount of mass flowing through a cross section per unit time. It is related to the **volume flow rate ($\dot{V}$)**, which is the volume of a fluid flowing through a cross section per unit time, by:

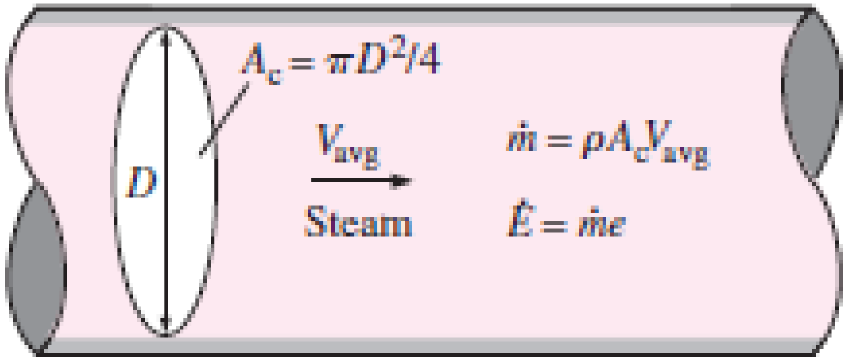
Mass flow rate and energy flow rate

$$\dot{m} = \rho\dot{V} = \rho(\overrightarrow{A_c}.\vec{v}) = \rho A_c v_{avg}\ (kg/s)$$

which is analogous to $m = \rho V$. Here ρ is the fluid density, A_c is the cross-sectional area of flow, and V_{avg} is the average flow velocity normal to A_c.

- Then the energy flow rate $\dot{E}$ associated with a fluid flowing at a rate of $\dot{m}$ is:

$$\dot{E} = \dot{m}e\ (Joule/second(J/s)or\ Watt\ (W))$$



Mass and energy flow rates associated with the flow of steam in a pipe of inner diameter D with an average velocity of V_{avg}.

Mechanical Energy

- **Mechanical energy: is the form of energy that can be converted completely and directly into mechanical work by an ideal mechanical device such as an *ideal turbine*. Kinetic and potential energies are the familiar forms of mechanical energy.**
- **Thermal energy *is not* mechanical energy, however, since it cannot be converted to work directly and completely (the second law of thermodynamics).**
- **Flow work: is the pressure force acting on a fluid through a distance.**

$$e_{mech} = \frac{p}{\rho} + \frac{v^2}{2} + gz \quad \text{(Energy potential)}$$

Mechanical Energy

Or in rate form:

$$\dot{E}_{mech} = \dot{m}\left(\frac{p}{\rho} + \frac{v^2}{2} + gz\right) \text{ (rate of energy potential)}$$

Then the mechanical energy change of a fluid during incompressible flow (ρ = constant) becomes:

$$\Delta e_{mech} = \left[\frac{p_2 - p_1}{\rho} + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1)\right]$$

and in rate form is:

$$\Delta \dot{E}_{mech} = \dot{m}\left[\frac{p_2 - p_1}{\rho} + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1)\right]$$

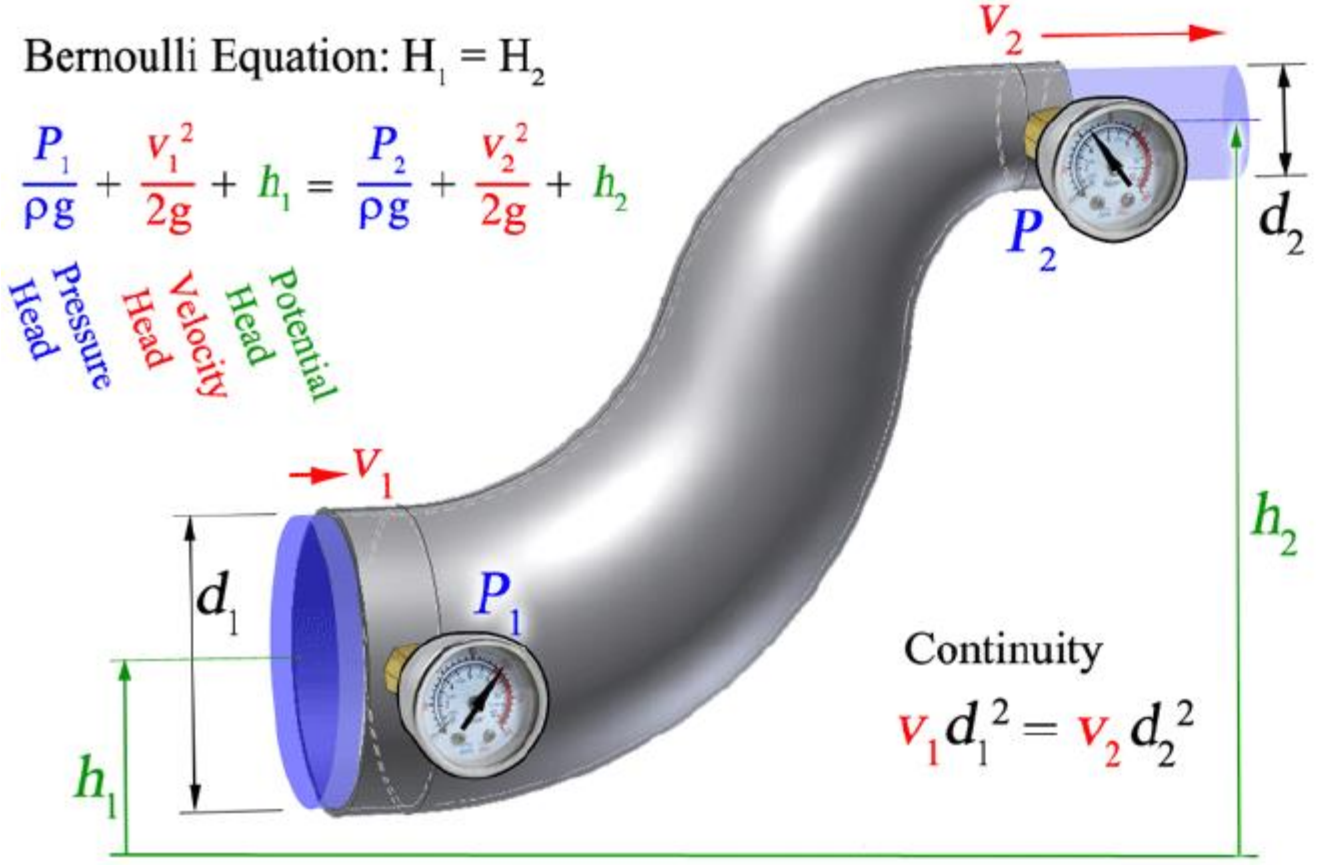
Mechanical Energy

- $\Delta \dot{E}_{mech}$ can be positive, negative or zero!!!

A. $\Delta \dot{E}_{mech} = 0$:

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{v_2^2}{2} + gz_2$$

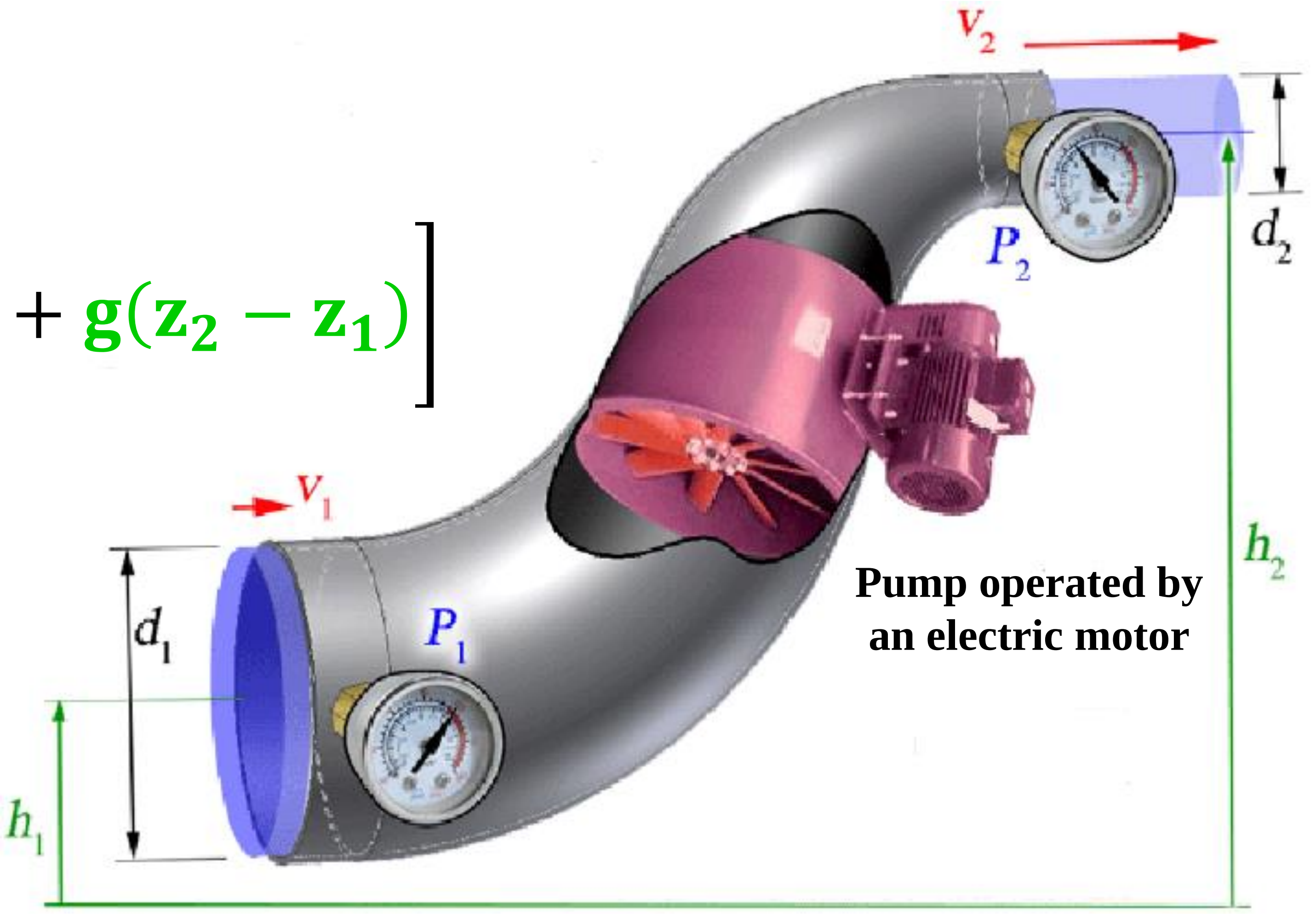
Pressure (flow) energy, Kinetic energy, Potential energy



Mechanical Energy

B. $\Delta\dot{E}_{mech} > 0$:

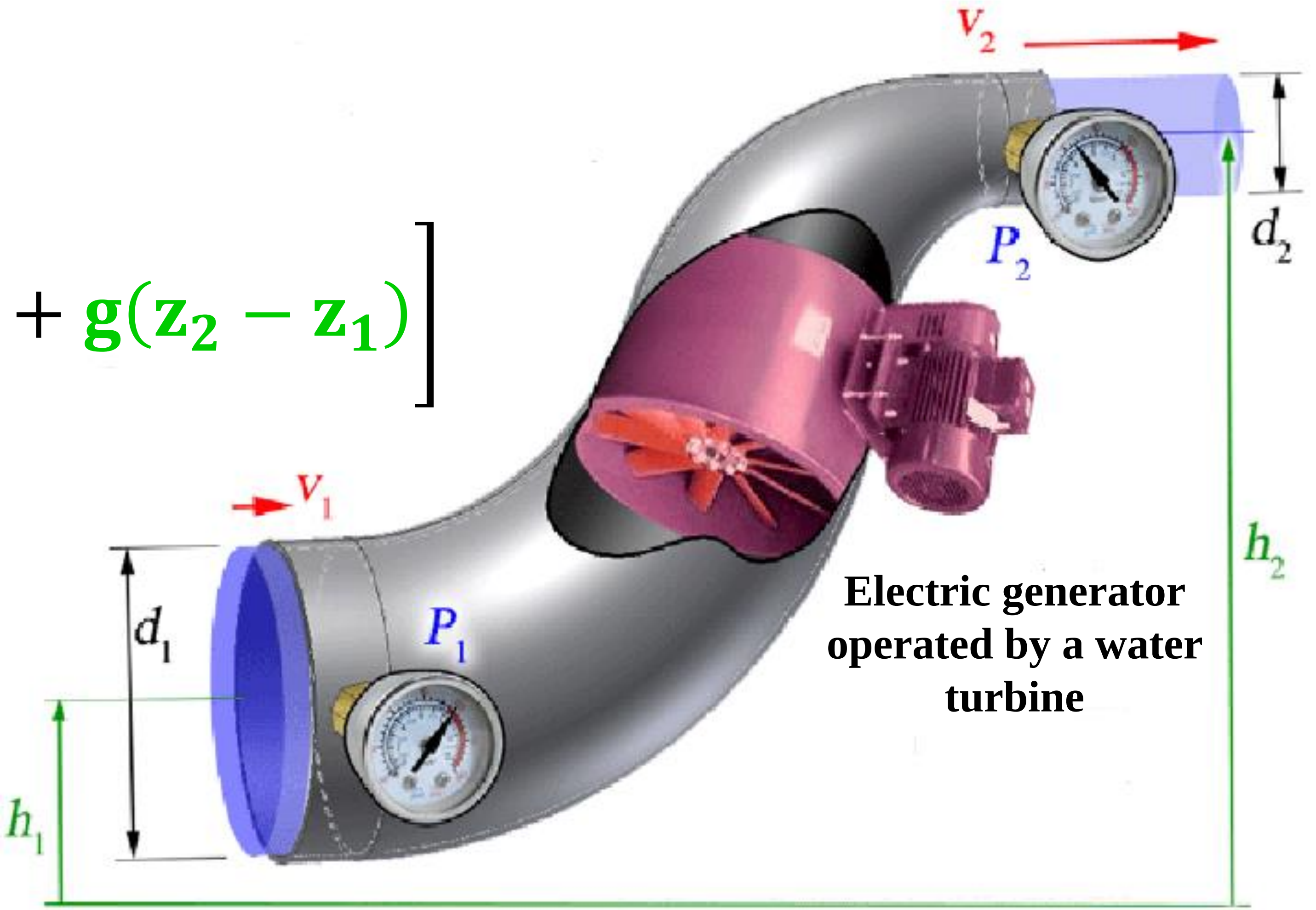
$$\Delta\dot{E}_{mech} = \dot{m}\left[\frac{p_2 - p_1}{\rho} + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1)\right]$$



Mechanical Energy

C. $\Delta \dot{E}_{mech} < 0$:

$$\Delta \dot{E}_{mech} = \dot{m}\left[\frac{p_2 - p_1}{\rho} + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1)\right]$$



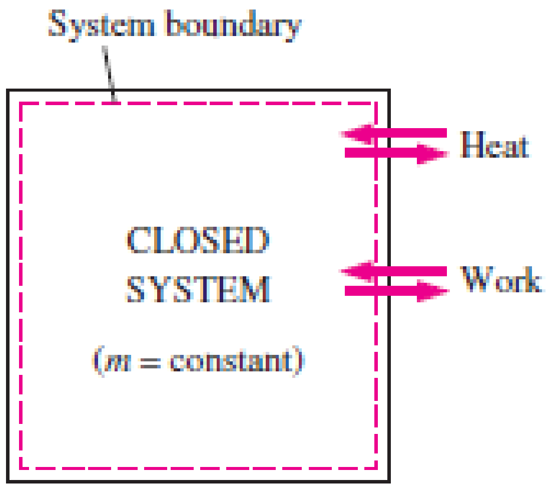
Electric generator operated by a water turbine

3. ENERGY TRANSFER BY WORK

3. ENERGY TRANSFER BY WORK

- **Energy can cross the boundary of a closed system in two distinct forms: work and heat.**
- **Work: is an energy interaction that is not caused by temperature difference between a system and its surroundings.**
- **The work done per unit time is called power ($\dot{W}$) and its unit is Watt (W).**
- **The work done per unit mass of a system is denoted by w and is expressed as:**

$$w = \frac{W}{m} \ (J/kg)$$

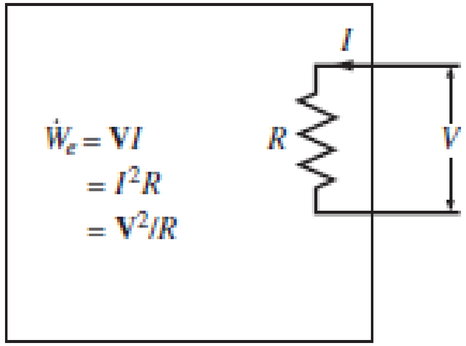


Energy can cross the boundaries of a closed system in the form of heat and work.

3. ENERGY TRANSFER BY WORK

A. Electrical Work:

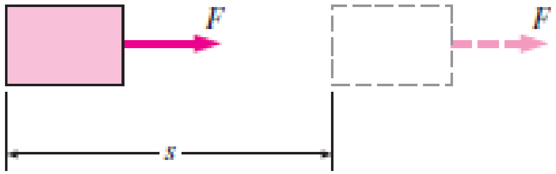
$$W_e = \int_1^2 VIdt$$



Electrical power in terms of resistance R, current I, and potential difference V.

B. Displacement Work:

$$W_d = \int_1^2 Fds$$



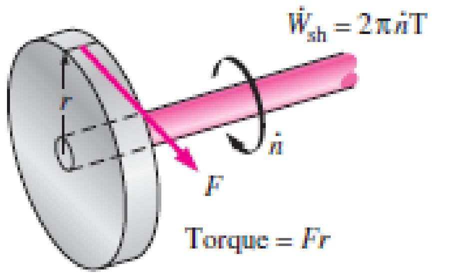
The work done is proportional to the force applied (F) and the distance traveled (s).

3. ENERGY TRANSFER BY WORK

C. Shaft Work:

$$W_{sh} = \text{Force x distance} = \left(\frac{T}{r}\right).2\pi rn = 2\pi nT$$

$$\dot{W}_{sh} = 2\pi\dot{n}T$$



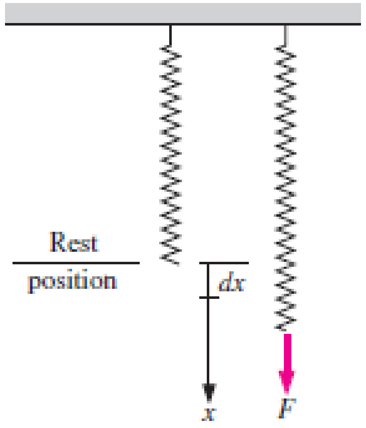
Shaft work is proportional to the torque applied and the number of revolutions of the shaft.

D. Spring Work:

$F_{sp} = Kx,$ where K is the spring constant

$$W_{sp} = \int_1^2 F_{sp}\,dx = \int_1^2 Kx\,dx$$

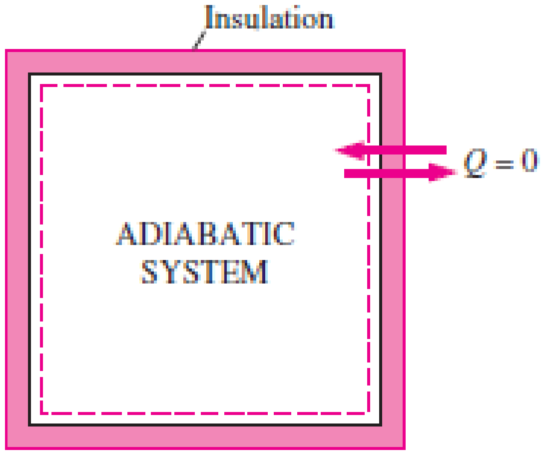
$$W_{sp} = \frac{1}{2}K\left(X_2^2 - X_1^2\right)$$



Elongation of a spring under the influence of a force.

4. ENERGY TRANSFER BY HEAT

- **Heat:** is the form of energy that is transferred between a system and its surroundings by the potential of temperature difference.
- A process during which there is no heat transfer is called an **adiabatic process**.



Insulated system ≡ Adiabatic system

Adiabatic process ≡ No heat transfer (Q=0)

- Heat transfer per unit mass of a system is denoted **q** and is expressed as:

$$q = \frac{Q}{m} \ (J/kg)$$

- **Heat transfer rate ($\dot{Q}$):** is the heat transfer per unit time.

4. ENERGY TRANSFER BY HEAT

Heat

Conduction: The transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones.

Convection: The transfer of energy between a solid surface and the adjacent fluid that is in motion.

Radiation: The transfer of energy due to the emission of electromagnetic waves.

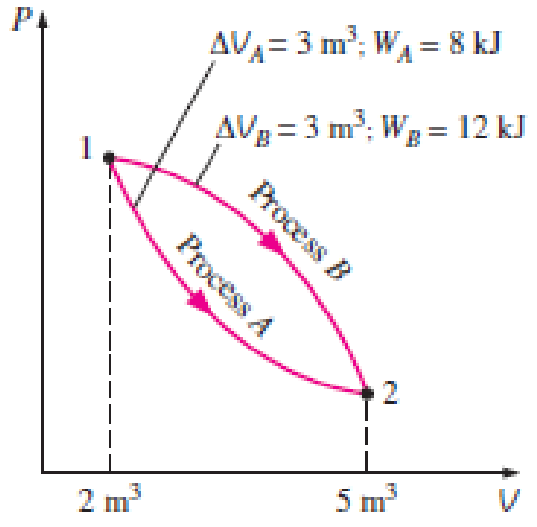
Point and path functions

- **Properties** are **point functions**. They depend on the state only, and not on how a system reaches that state.
- **Heat** and **work** are **path function**. Each is not a property and systems do not possess **work** or **heat** at a state.

$$\mathbf{W} = \int_1^2 \delta W \neq W_2 - W_1$$

$$\mathbf{Q} = \int_1^2 \delta q \neq q_2 - q_1$$

Meaningless !!!



Properties are point functions; but heat and work are path functions (their magnitudes depend on the path followed).