Energy

Fundamental concept of thermodynamics.

One of the *most significant aspects* of engineering analysis.

Create list examples of energy generation or consumption in our daily lives

Conservation of Energy:

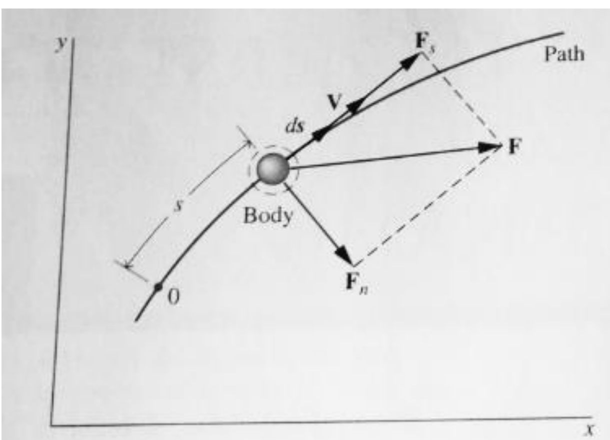
- The total amount of energy in the system is conserved

Energy can be: *stored*, *transformed* or *transferred*

Newton formulated a general description of motion under applied forces, which led to the concepts of:

- Work
- Kinetic Energy
- Potential Energy

Nomenclature



Where:

- F = force acting on the body in motion
- F_s = force component along path or 'streamline'. Affects **magnitude**.
- F_n = force component normal to the path. Affects **direction**.
- F = F{s}

$$F_s = m\frac{dv}{dt}$$

$$F_s = m\frac{dv}{ds}\frac{ds}{dt} = mv\frac{dv}{ds}$$

$$\int_{v1}^{v2} mvdv = \int_{s1}^{s2} F_s ds$$

Work

Kinetic energy

$$\int_{v1}^{v2} mvdv = \frac{1}{2}mv^2\Big]_{v1}^{v2} = \frac{1}{2}m(v_2^2 - v_1^2)$$

Kinetic Energy: Change in kinetic energy = $\frac{1}{2}m(v_2^2 - v_1^2)$

Work: The work of the resultant force on the body equals the change in it's kinetic energy.

Units

- Metric = $N \cdot m = J$
- $Imperial = Btu$

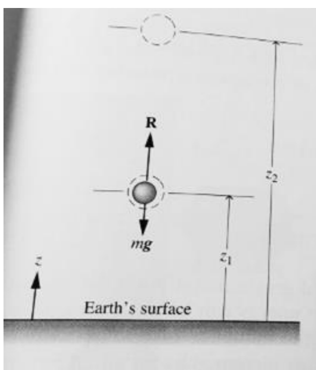
General equation:

$$\frac{1}{2}m(v_2^2 - v_1^2) = \int_{s1}^{s2} F \cdot ds$$

Work done by the body can be considered a transfer of energy to the body, where it is stored as kinetic energy.

Potential Energy

The energy that an object has due to its position in a force field or that a system has due to the configuration of its parts.



Where:

- mg = force due to gravity
- R = resultant of all other forces acting on the system

Apply governing equation for multiple forces in the z direction:

$$\frac{1}{2}m(v_2^2 - v_1^2) = \int_{z1}^{z2} R \cdot dz - \int_{z1}^{z2} mg \cdot dz$$

$$\int_{z1}^{z2} mg \cdot dz = mg(z_2 - z_1)$$

Therefore:

$$\frac{1}{2}m(v_2^2 - v_1^2) + mg(z_2 - z_1) = \int_{z1}^{z2} R \cdot dz$$

Gravitational potential energy = mgz

Work

$$W = \int_{s1}^{s2} F \cdot ds$$

A means of transferring energy

Work is done by a system on it's surroundings if the sole effect on everything external to the system *could have been* the raising of a weight.

This is very analogous to mechanics.

Sign conventions:

- W > 0: Work is done *by* the system
- W < 0: Work is done *on* the system

Power

The rate of energy transfer by work = $\dot{W}$ or P

$$\dot{W} = F \cdot v$$

Therefore

$$W = \int_{t1}^{t2} \dot{W} dt = \int_{t1}^{t2} F \cdot v \, dt$$

Expansion or Compression Work

Piston -cylinder assembly

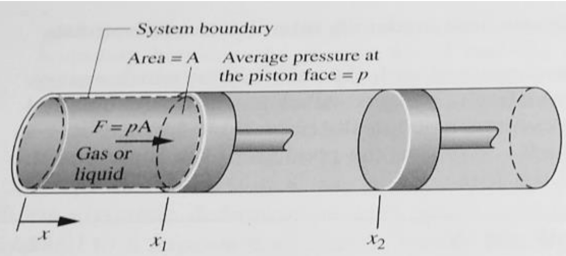


Figure 2.4 Expansion or compression of a gas or liquid.

$$\delta W = pAdx = pdV$$

$$\boxed{W = \int_{V1}^{V2} pdV}$$

Power Transmitted by a Shaft

A rotating shaft with angular velocity, ω, and exerting a torque, T, on it's surroundings produces the following power:

$$\dot{W} = F_t v = \left(\frac{\mathrm{T}}{\mathrm{R}}\right)(\mathrm{R}\omega) = \omega \mathrm{T}$$

$$\boxed{\dot{W} = 2\pi n T}$$

Where:

- R = radius
- F_t= tangential force
- n = shaft speed

First Law of Thermodynamics

The law of conservation of energy states that **the total energy of an isolated system is constant**; energy can be transformed from one form to another, but cannot be created or destroyed.

Adiabatic process - No thermal interactions between the system and it's surroundings

Change in energy between two states: $E_2 - E_1 = -W_{ad}$

Where W_{ad} = net work for any adiabatic process between two states. Negative sign means work done *on* the system.

Internal Energy

E denotes total energy, including kinetic, potential energy, and others. These 'others' are considered internal energy, *U*.

Examples of internal energy:

1. Compress a spring
2. Charge a battery
3. Others?

Therefore, the change in total energy of the system is defined as:

$$\Delta E = \Delta KE + \Delta PE + \Delta U \text{ (for an adiabatic process)}$$

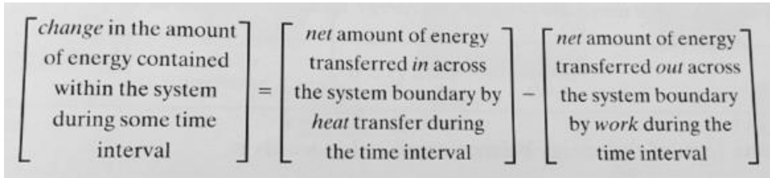
Heat Transfer

Non-Adiabatic Process - A process that involves a thermal interaction between a system and it's surroundings.

Energy transfer *Q* is only induced as a result of temperature difference between the system and the surroundings and only occurs in the direction of decreasing temperature. *Energy transfer by heat*.

$$Q = (E_2 - E_1) + W, \text{ or}$$

$$\boxed{\Delta KE + \Delta PE + \Delta U = Q - W}$$



[*change* in the amount of energy contained within the system during some time interval] = [*net* amount of energy transferred *in* across the system boundary by *heat* transfer during the time interval] − [*net* amount of energy transferred *out* across the system boundary by *work* during the time interval]

Sign conventions (opposite of work):

- $Q > 0$: heat transfer *to* the system
- $Q < 0$: heat transfer *from* the system

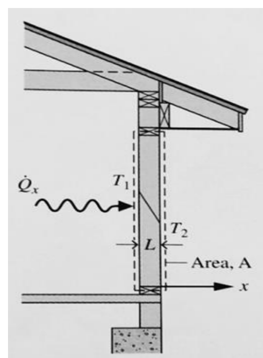
Heat transfer rate, $\dot{Q}$, is the amount of heat transfer per unit time. $Q = \int_{t1}^{t2} \dot{Q} dt$

Heat flux: $\dot{Q} = \int_A \dot{q} dA =$, where $\dot{q}$ is heat transfer per unit area.

Heat Transfer Mechanisms

Conduction: Energy transfer in solids, liquids or gases. The rate of heat transfer across any plane normal to the x direction, $\dot{Q}_x$, is proportional to the wall area, A and temperature gradient in the x direction.

$$\dot{Q}_x = -kA\left[\frac{T_2 - T_1}{L}\right]$$



Where:

- k = thermal conductivity (available in tables)
- L is the wall thickness

Thermal radiation: Emitted by mater as a result of changes in the electronic configuration of the atoms or molecules within it.

Energy is transported by electromagnetic waves. No intervening medium is required and can therefore occur in a vacuum.

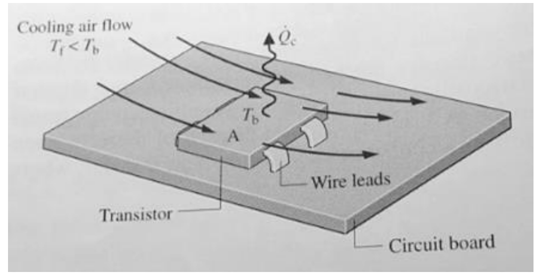
$$\dot{Q}_e = \varepsilon \sigma A T_b^4$$

Where:

- T_b is temperature of the surface
- ε is the emissivity, a property of the surface. How effectively it radiates.
- σ is the Stefan-Boltzmann constant.
- Highly sensitive to temperature, T_b

Convection: Energy transfer between a solid surface at T_b and the adjacent moving gas or liquid at temperature T_f.

$$\dot{Q}_c = hA(T_b - T_f)$$



Where:

- *h* is the heat transfer coefficient

Forced convection - when fans or pumps cause the fluid to move

Natural convection - buoyancy induced motion

Applications	h (W/m²·K)	h (Btu/h · ft² · °R)
Free convection		
Gases	2–25	0.35–4.4
Liquids	50–1000	8.8–180
Forced convection		
Gases	25–250	4.4–44
Liquids	50–20,000	8.8–3500

So what comes next?

1. Control volume energy analysis
   a. Open systems with energy transfer through a moving fluid
   b. Application of continuity and energy balance
2. Property relations
3. Thermodynamic cycles