0905322- Chemical Engineering Thermodynamics I
Lecture 4: Interactions

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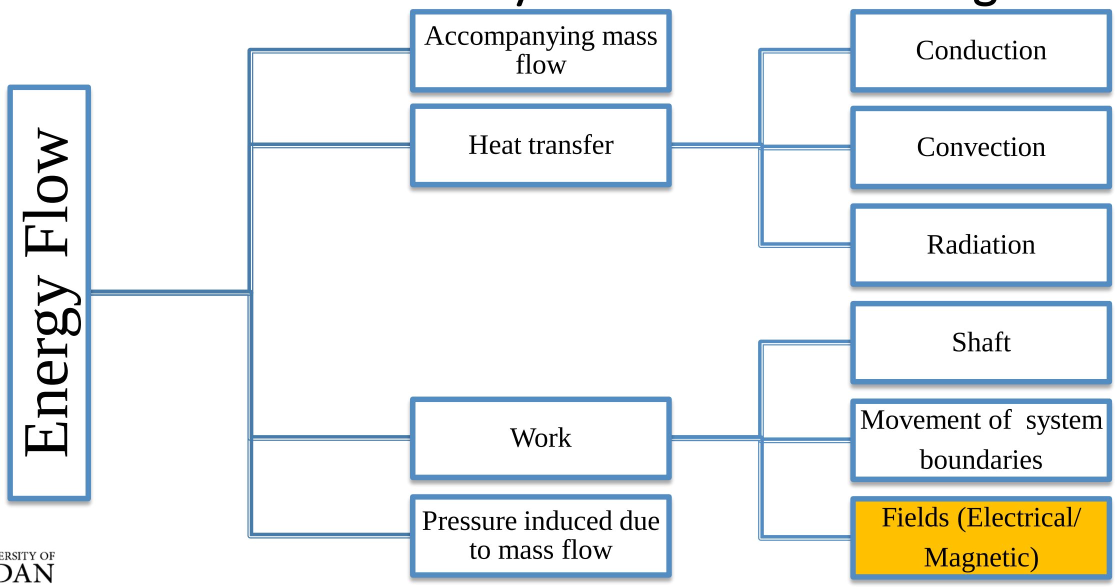
Outline

- Interactions Between a System and Surroundings
- Energy Accompanying Mass Flow
- Heat and Work Characteristics
- Heat Transfer
- Work
  - Mechanical Work
  - Electrical Work
  - Shaft Work
- Energy Conversion Efficiencies

Interactions Between a System and Surroundings



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Energy Accompanying Mass Flow

- Mass flow occurs at the system boundary.
- An inlet/outlet stream carries energy with it in the form of: kinetic, potential, internal and flow induced energy

$$E_{\text{mass flow}} = \left(h_i + \frac{V_i^2}{2} + g z_i \right)$$

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Heat and Work Characteristics

- Heat and work are interactions between the system and its surroundings.
- Heat and work are similar in some aspects
  - **Boundary** phenomena.
  - Systems possess energy, but not heat or work. That is heat and work are **transient** phenomena.
  - Both are **associated with a process** not a state.
  - Both are **path functions** i.e., their magnitude depend on the path followed by a process as the end states.
  - Both are **directional quantities**. You have to give the proper sign or direction of heat and work.

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Heat Transfer

- **Heat** is the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a **temperature difference**. **ENERGY IN TRANSIT**.
- Heat transferred **to** the system is **positive**, while heat transferred **from** the system is **negative**.
- Units of energy are kJ, while the units of heat transfer rate are in kJ/s or kW.

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Modes of Heat Transfer

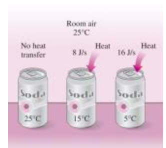
Conduction

Transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. (G,L,S)

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

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

Energy emitted by matter in the form of electromagnetic waves (photons) as a result of the changes in the electronic configurations of the atoms or molecules.
Does not require an intervening medium.
Usually important at high temperatures.



Energy transfer between a solid surface and the adjacent fluid (G, or L) which is in motion.

Radiation ⟷ **Convection**

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

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Adiabatic Process

- A process with no heat transfer is called an adiabatic process. It can occur in two ways:
  - Well insulated system.
  - Both the system and surroundings are at the same T, which means there is no driving force.
- The temperature of the system may change in an adiabatic process by other means such as work.

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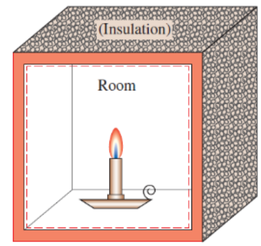
EXAMPLE 2–3 Burning of a Candle in an Insulated Room

A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine (a) if there is any heat transfer during this burning process and (b) if there is any change in the internal energy of the system.



SOLUTION A candle burning in a well-insulated room is considered. It is to be determined whether there is any heat transfer and any change in internal energy.
Analysis (*a*) The interior surfaces of the room form the system boundary, as indicated by the dashed lines in Fig. 2–23. As pointed out earlier, heat is recognized as it crosses the boundaries. Since the room is well insulated, we have an adiabatic system, and no heat will pass through the boundaries. Therefore, $Q = 0$ for this process.
(*b*) The internal energy involves energies that exist in various forms (sensible, latent, chemical, nuclear). During the process just described, part of the chemical energy is converted to sensible energy. Since there is no increase or decrease in the total internal energy of the system, $\Delta U = 0$ for this process.

EXAMPLE 2–4 Heating of a Potato in an Oven

A potato initially at room temperature (25°C) is being baked in an oven that is maintained at 200°C, as shown in Fig. 2–24. Is there any heat transfer during this baking process?

SOLUTION

A potato is being baked in an oven. It is to be determined whether there is any heat transfer during this process.

Analysis This is not a well-defined problem since the system is not specified. Let
us assume that we are observing the potato, which will be our system. Then the outer surface of the skin of the potato can be viewed as the system boundary. Part of the energy in the oven will pass through the skin to the potato. Since the driving force for this energy transfer is a temperature difference, this is a heat transfer process.

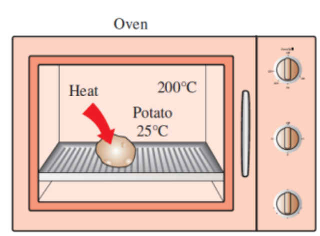


FIGURE 2–24
Schematic for Example 2–4.

Mechanical Work

- Work is a mechanism for transporting energy across the boundaries of the system.
- Mechanical work is the product of a force F and a displacement Δx when both are measured in the same direction (collinear).
- Work done on the system is negative, while work done by the system is positive.
- Units of work are kJ, while the units of time rate at which work is done on or by the system (power) are in kJ/s or kW.

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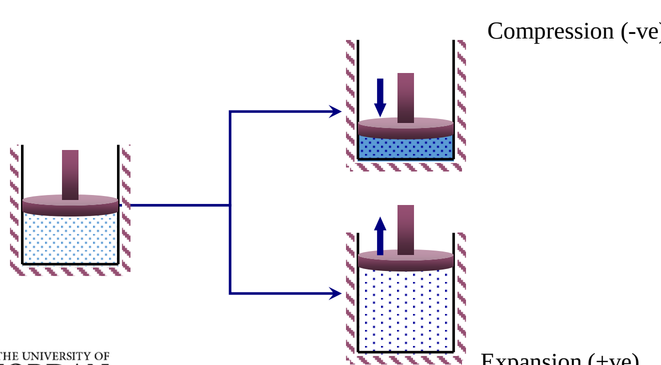
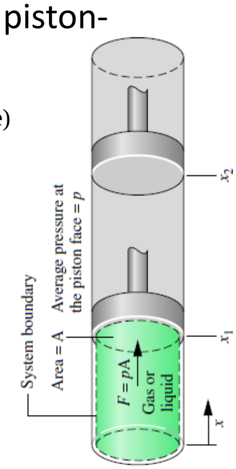
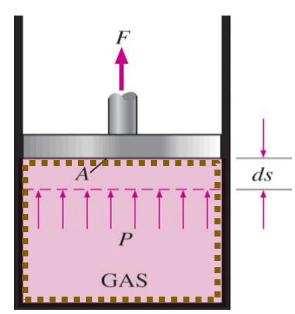
Moving Boundary Work (W_b)

- Moving boundary work ($P\mathrm{d}V$ work): The expansion and compression work in a piston-cylinder device.







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

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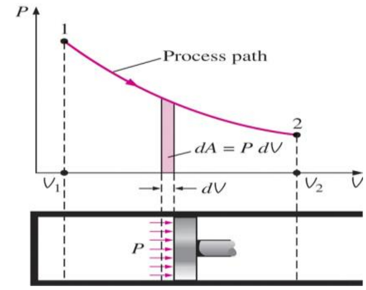
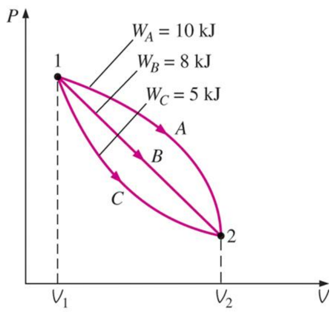
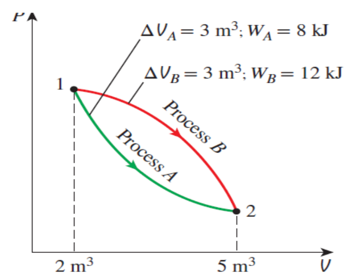
Work as An Area Under P-V Curve



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

$$\text{Area} = A = \int_1^2 \delta W = \int_1^2 dA = \int_1^2 PdV = W_{12}\left(\text{not } \Delta W\right) = W_b$$





Units of Pressure in Pa and units of volume in m^3 to obtain work in Joules (J).

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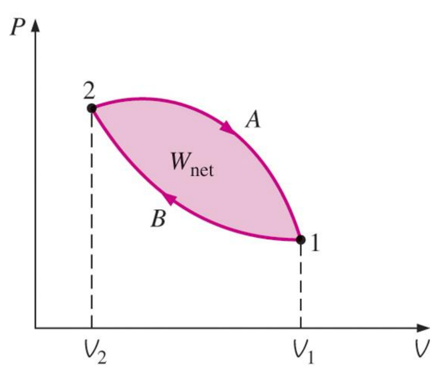
Work in a Cycle

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



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Polytropic, Isothermal, and Isobaric Processes

- Polytropic mean “turning many ways”.
- Polytropic process is the general case for the different processes.
- For a constant polytropic exponent *n*

Process	*n*
Isobaric	0
isothermal	1
Isochoric	∝
Isentropic (adiabatic reversible)	γ

$$PV^{n} = C$$
$$P_1V_1^{n} = P_2V_2^{n} = C$$
$$T_1V_1^{n-1} = T_2V_2^{n-1} = C$$
$$T_1P_1^{\frac{1-n}{n}} = T_2P_2^{\frac{1-n}{n}} = C$$

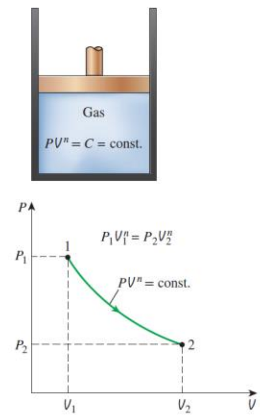

FIGURE 4–9
Schematic and *P*-*V* diagram for a polytropic process.

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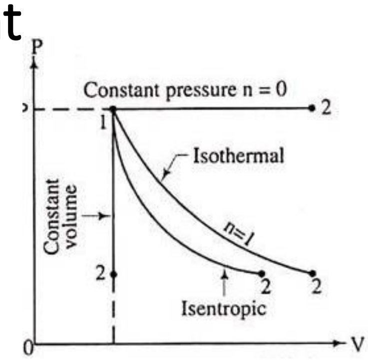
Polytropic Process: Work and Heat

$$\Delta u = c_V (T_2 - T_1)$$
$$\Delta h = c_P (T_2 - T_1)$$
$$Q = c_V \frac{(\gamma - n)}{(1-n)}(T_2 - T_1)$$



$$w_b = \int_1^2 PdV = \int_1^2 CV^{-n}dV = C\frac{V_2^{1-n} - V_1^{1-n}}{1-n} = \frac{1}{n-1}(P_2V_2 - P_1V_1), \quad n \neq 1$$
$$w_b = \int_1^2 PdV = \int_1^2 CV^{-1}dV == PV \ln\left(\frac{V_2}{V_1}\right), \quad n = 1$$

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EXAMPLE 4–4 Expansion of a Gas Against a Spring

A piston–cylinder device contains 0.05 m³ of a gas initially at 200 kPa. At this state, a linear spring that has a spring constant of 150 kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross sectional area of the piston is 0.25 m², determine (*a*) the final pressure inside the cylinder, (*b*) the total work done by the gas, and (*c*) the fraction of this work done against the spring to compress it.

SOLUTION A gas in a piston–cylinder device equipped with a linear spring expands as a result of heating. The final gas pressure, the total work done, and the fraction of the work done to compress the spring are to be determined.

Assumptions **1** The expansion process is quasi-equilibrium. **2** The spring is linear in the range of interest.

Analysis A sketch of the system and the *P-V* diagram of the process are shown in Fig. 4–10.

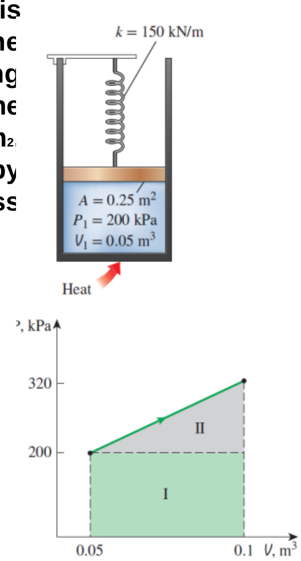

FIGURE 4–10
Schematic and *P-V* diagram for Example 4–4.

(*a*) The enclosed volume at the final state is

$$V_2 = 2V_1 = (2)(0.05\ \text{m}^3) = 0.1\ \text{m}^3$$

Then the displacement of the piston (and of the spring) becomes

$$x = \frac{\Delta V}{A} = \frac{(0.1 - 0.05)\text{m}^3}{0.25\ \text{m}^3} = 0.2\ \text{m}$$

The force applied by the linear spring at the final state is

$$F = kx = (150\ \text{kN/m})(0.2\ \text{m}) = 30\ \text{kN}$$

The additional pressure applied by the spring on the gas at this state is

$$P = \frac{F}{A} = \frac{30\ \text{kN}}{0.25\ \text{m}^2} = 120\ \text{kPa}$$

Without the spring, the pressure of the gas would remain constant at 200 kPa while the piston is rising. But under the effect of the spring, the pressure rises linearly from 200 kPa to

$$200 + 120 = \mathbf{320\ kPa}$$

at the final state.

(*b*) An easy way of finding the work done is to plot the process on a *P*-*V* diagram and find the area under the process curve. From Fig. 4–10 the area under the process curve (a trapezoid) is determined to be

$$W = \text{area} = \frac{(200 + 320)\ \text{kPa}}{2}[(0.1 - 0.05)\ \text{m}^3]\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = \mathbf{13\ kJ}$$

Note that the work is done by the system.

(*c*) The work represented by the rectangular area (region I) is done against the piston and the atmosphere, and the work represented by the triangular area (region II) is done against the spring. Thus,

$$W_{\text{spring}} = \tfrac{1}{2}[(320 - 200)\ \text{kPa}](0.05\ \text{m}^3)\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = \mathbf{3\ kJ}$$

Discussion This result could also be obtained from

$$W_{\text{spring}} = \tfrac{1}{2}k(x_2^2 - x_1^2) = \tfrac{1}{2}(150\ \text{kN/m})[(0.2\ \text{m})^2 - 0^2]\left(\frac{1\ \text{kJ}}{1\ \text{kN}\cdot\text{m}}\right) = 3\ \text{kJ}$$

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A rigid tank contains air at 500 kPa and 150°C. As a result of heat transfer to the surroundings, the temperature and pressure inside the tank drop to 65°C and 400 kPa, respectively. Determine the boundary work done during this process.

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Heat Capacity

- The heat required to raise a unit mass of a substance by one degree (scale dependent).
  - Constant volume (isochoric)

$$c_V = \left(\frac{\partial u}{\partial T}\right)_V$$

  - Constant pressure (isobaric)

$$c_P = \left(\frac{\partial h}{\partial T}\right)_P$$

- Units in (kJ/kg.K or kJ/mol.K). Same as units of entropy *S*.

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Ideal Gas c_V and c_P

- Ideal gas is a simple case in which an exact relationship exists between the two heat capacities.
- The enthalpy and internal energy of an ideal gas are functions of temperature only
  - Heat capacity is a function of temperature only.
  - Partial derivatives can be replaced by total derivatives (pressure independent).
- Ideal gas heat capacities are usually tabulated as a polynomial in temperature

$$c_P^* = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + \cdots$$

$$c_v^*(T) = \left(\frac{du(T)}{dT}\right)$$

$$c_P^*(T) = \left(\frac{dh(T)}{dT}\right)$$

$$h = u + Pv = u + RT$$

$$\Downarrow$$

$$c_P^*(T) = c_V^*(T) + R$$

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TABLE A–2

Ideal-gas specific heats of various common gases (*Concluded*)

(*c*) As a function of temperature

$$\bar{c}_p = a + bT + cT^2 + dT^3$$

(T in K, c_p in kJ/kmol·K)

Substance	Formula	a	b	c	d	Temperature range, K	% error Max.	% error Avg.
Nitrogen	N_2	28.90	-0.1571×10^{-2}	0.8081×10^{-5}	-2.873×10^{-9}	273–1800	0.59	0.34
Oxygen	O_2	25.48	1.520×10^{-2}	-0.7155×10^{-5}	1.312×10^{-9}	273–1800	1.19	0.28
Air	—	28.11	0.1967×10^{-2}	0.4802×10^{-5}	-1.966×10^{-9}	273–1800	0.72	0.33
Hydrogen	H_2	29.11	-0.1916×10^{-2}	0.4003×10^{-5}	-0.8704×10^{-9}	273–1800	1.01	0.26
Carbon monoxide	CO	28.16	0.1675×10^{-2}	0.5372×10^{-5}	-2.222×10^{-9}	273–1800	0.89	0.37
Carbon dioxide	CO_2	22.26	5.981×10^{-2}	-3.501×10^{-5}	7.469×10^{-9}	273–1800	0.67	0.22
Water vapor	H_2O	32.24	0.1923×10^{-2}	1.055×10^{-5}	-3.595×10^{-9}	273–1800	0.53	0.24
Nitric oxide	NO	29.34	-0.09395×10^{-2}	0.9747×10^{-5}	-4.187×10^{-9}	273–1500	0.97	0.36
Nitrous oxide	N_2O	24.11	5.8632×10^{-2}	-3.562×10^{-5}	10.58×10^{-9}	273–1500	0.59	0.26
Nitrogen dioxide	NO_2	22.9	5.715×10^{-2}	-3.52×10^{-5}	7.87×10^{-9}	273–1500	0.46	0.18
Ammonia	NH_3	27.568	2.5630×10^{-2}	0.99072×10^{-5}	-6.6909×10^{-9}	273–1500	0.91	0.36
Sulfur	S	27.21	2.218×10^{-2}	-1.628×10^{-5}	3.986×10^{-9}	273–1800	0.99	0.38

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Obtaining Internal Energy

- Gases:
  - Exact expression for an ideal gas.
  - Valid only when density = constant for a real gas.

$$\Delta u = \int_{T_1}^{T_2} c_V^*(T)\,dT$$

- Solids and liquids

$$\Delta u = \Delta h - \Delta(Pv) \approx \Delta h - v\,\Delta P \approx \int_{T_1}^{T_2} c_P^*(T)\,dT$$

  - Reasonable approximation for a solid or a liquid below T_r= 0.75 (pressure change is below several MPa).

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Obtaining Enthalpy

- Gases:
  - Exact expression for an ideal gas.
  - Valid only when density = constant for a real gas.

$$\Delta h = \int_{T_1}^{T_2} c_P^*(T)dT$$

- Solids and liquids

$$\Delta h \approx \int_{T_1}^{T_2} c_P^*(T)dT + v\Delta P \approx \int_{T_1}^{T_2} c_P^*(T)dT$$

  - Reasonable approximation for a solid or a liquid below $T_r = 0.75$ (pressure change is below several MPa).

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Ideal Gas Heat Capacities

- Assuming the isochoric and isobaric **heat capacities are constant**, define their ratio γ

$$\gamma = \frac{c_P}{c_V}$$

Example gases	c_P	c_V	γ
Monoatomic (Ar, Kr, Xe)	5/2 R	3/2 R	1.67
Diatomic (O_2, H_2, N_2)	7/2 R	5/2 R	1.40
Simple polyatomic (CO_2, SO_2, NH_3, CH_4)	≈ 9/2 R	≈ 7/2 R	1.30

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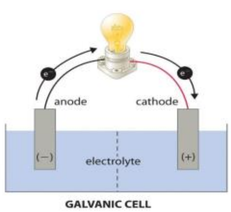
Electrical Work

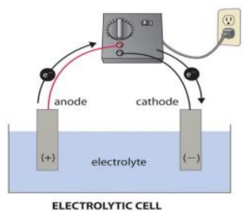
- Flow of electrical energy is classified as shaft work and is given by the product of current flow (I in Amperes) and electrical potential difference across the system (V in Volts)

$$\dot{W}_e\,(\mathrm{W}) = VI\,, \qquad W_e\,(\mathrm{J}) = VI\,\Delta t = VN$$

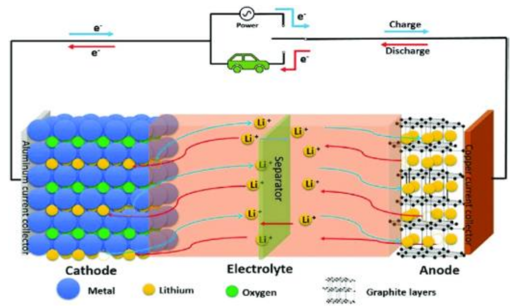
- **Negative** if electrical energy is supplied to the system, and **Positive** if the system is the source of electrical energy.



Energy released by spontaneous redox reaction is converted to electrical energy.



Electrical energy is used to drive nonspontaneous redox reaction.



A cell phone Li-ion battery has the following specs: Voltage is 3.85 V and discharge rate is 2000 mAh.

a) Determine the energy discharge for this battery.

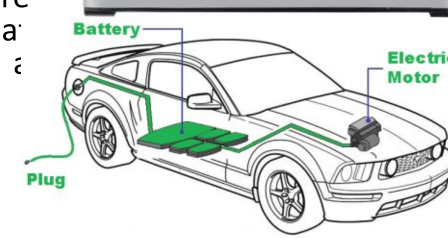
=(3.85)(2) = 7.7 W.h

b) Given that the mass of such a battery is 54 g, what is the energy density (W.h/kg)?

=7.7/.054 = 142.6 W.h/kg

c) The same energy density and battery are going to be used to drive an electrical vehicle. What would be the mass of the battery required for such a car if the capacity of the battery is 16 kW.h?

=16000/142.6 = 112.2 kg.



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Shaft Work

- Energy transmission with a rotating shaft is very common in engineering practice.
- Often the torque T applied to the shaft is constant, which means that the force F applied is also constant. For a specified constant torque, the work done during n revolutions is determined as follows:
  - A force F acting through a moment arm r generates a torque T of

$$T = Fr \rightarrow F = T / r$$

  - This force acts through a distance s, which is related to the radius r by

$$r = (2\pi r)n$$

  - Then the shaft work is determined from

$$W_{sh}(\mathrm{J}) = Fs = (T / r)(2\pi r)n = 2\pi nT$$

  - The power transmitted through the shaft is the shaft work done per unit time

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

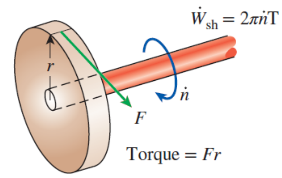
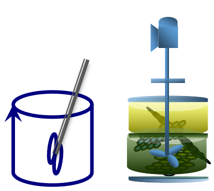
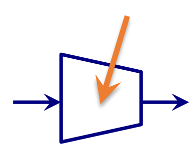


FIGURE 2–30
Shaft work is proportional to the torque applied and the number of revolutions of the shaft.

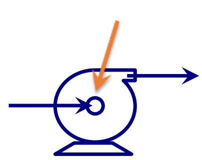
Shaft Work Examples



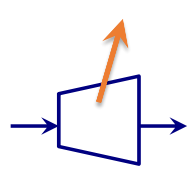
a) Mixing



c) Compression



b) Pumping



d) Expansion (Turbine)

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EXAMPLE 2–7 Power Transmission by the Shaft of a Car

Determine the power transmitted through the shaft of a car when the torque applied is 200 N · m and the shaft rotates at a rate of 4000 revolutions per minute (rpm).

SOLUTION The torque and the rpm for a car engine are given. The power transmitted is to be determined.

Analysis A sketch of the car is given in Fig. 2–31. The shaft power is determine directly from

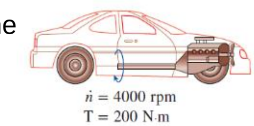

FIGURE 2–31
Schematic for Example 2–7.

$$\dot{W}_{sh} = 2\pi\dot{n}T = (2\pi)\left(4000\ \frac{1}{\text{min}}\right)(200\ \text{N·m})\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{N·m}}\right)$$
$$= \mathbf{83.8\ kW} \quad (\text{or } 112\ \text{hp})$$

Discussion Note that power transmitted by a shaft is proportional to torque and the
rotational speed.

EXAMPLE 2–10 Cooling of a Hot Fluid in a Tank

A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddle wheel.

SOLUTION A fluid in a rigid tank loses heat while being stirred. The final internal energy of the fluid is to be determined.

Assumptions **1** The tank is stationary and thus the kinetic and potential energy changes are zero, ΔKE = ΔPE = 0. Therefore, $\Delta E = \Delta U$ and internal energy is the only form of the system's energy that may change during this process. **2** Energy stored in the paddle wheel is negligible.

Analysis Take the contents of the tank as the system (Fig. 2–49). This is a *closed system* since no mass crosses the boundary during the process. We observe that the volume of a rigid tank is constant, and thus there is no moving boundary work. Also, heat is lost from the system, and shaft work is done on the system. Applying the energy balance on the system gives

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$W_{sh,in} - Q_{out} = \Delta U = U_2 - U_1$$

$$100\ \text{kJ} - 500\ \text{kJ} = U_2 - 800\ \text{kJ}$$

$$U_2 = \mathbf{400\ kJ}$$

Therefore, the final internal energy of the system is 400 kJ.

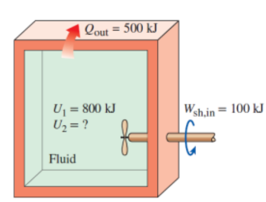

FIGURE 2–49
Schematic for Example 2–10.

EXAMPLE 2–11 Acceleration of Air by a Fan

A fan that consumes 20 W of electric power when operating is claimed to discharge air from a ventilated room at a rate of 1.0 kg/s at a discharge velocity of 8 m/s (Fig. 2–50). Determine if this claim is reasonable.

SOLUTION A fan is claimed to increase the velocity of air to a specified value while consuming electric power at a specified rate. The validity of this claim is to be investigated.

Assumptions The ventilating room is relatively calm, and air velocity in it is negligible.

Analysis First, let's examine the energy conversions involved: The motor of the fan converts part of the electrical power it consumes to mechanical (shaft) power, which is used to rotate the fan blades in air. The blades are shaped such that they impart a large fraction of the mechanical power of the shaft to air by mobilizing it. In the limiting ideal case of no losses (no conversion of electrical and mechanical energy to thermal energy) in steady operation, the electric power input will be equal to the rate of increase of the kinetic energy of air. Therefore, for a control volume that encloses the fan-motor unit, the energy balance can be written as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt^{\nearrow 0 \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0 \rightarrow \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{elect,in} = \dot{m}_{air} \text{ke}_{out} = \dot{m}_{air} \frac{V_{out}^2}{2}$$

Solving for V_{out} and substituting gives the maximum air outlet velocity to be

$$V_{out} = \sqrt{\frac{2\dot{W}_{elect,in}}{\dot{m}_{air}}} = \sqrt{\frac{2(20 \text{ J/s})}{1.0 \text{ kg/s}} \left(\frac{1 \text{ m}^2/\text{s}^2}{1 \text{ J/kg}} \right)} = 6.3 \text{ m/s}$$

which is less than 8 m/s. Therefore, the claim is false.

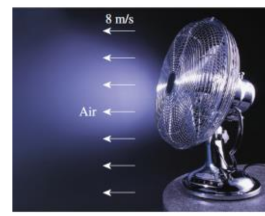

FIGURE 2–50
Schematic for Example 2–11.
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EXAMPLE 2–13 Annual Lighting Cost of a Classroom

The lighting needs of a classroom are met by 30 fluorescent lamps, each consuming 80 W of electricity (Fig. 2– 2). The lights in the classroom are kept on for 12 hours a day and 250 days a year. For a unit electricity cost of 11 cents per kWh, determine the annual energy cost of lighting for this classroom. Also, discuss the effect of lighting on the heating and air-conditioning requirements of the room.

SOLUTION The lighting of a classroom by fluorescent lamps is considered. The annual electricity cost of lighting for this classroom is to be determined, and the lighting's effect on the heating and air-conditioning requirements is to be discussed.

Assumptions The effect of voltage fluctuations is negligible, so each fluorescent lamp consumes its rated power.

Analysis The electric power consumed by the lamps when all are on and the number of hours they are kept on per year are

$$\begin{aligned} \text{Lighting power} &= (\text{Power consumed per lamp}) \times (\text{No. of lamps}) \\ &= (80 \text{ W/lamp})(30 \text{ lamps}) \\ &= 2400 \text{ W} = 2.4 \text{ kW} \end{aligned}$$

$$\text{Operating hours} = (12 \text{ h/day})(250 \text{ days/year}) = 3000 \text{ h/year}$$

Then the amount and cost of electricity used per year become

$$\begin{aligned} \text{Lighting energy} &= (\text{Lighting power})(\text{Operating hours}) \\ &= (2.4 \text{ kW})(3000 \text{ h/year}) = 7200 \text{ kWh/year} \end{aligned}$$

$$\begin{aligned} \text{Lighting cost} &= (\text{Lighting energy})(\text{Unit cost}) \\ &= (7200 \text{ kWh/year})(\$0.11/\text{kWh}) = \mathbf{\$792/year} \end{aligned}$$

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Light is absorbed by the surfaces it strikes and is converted to thermal energy. Disregarding the light that escapes through the windows, the entire 2.4 kW of electric power consumed by the lamps eventually becomes part of thermal energy of the classroom. Therefore, the lighting system in this room reduces the heating requirements by 2.4 kW but increases the air-conditioning load by 2.4 kW.

Discussion Note that the annual lighting cost of this classroom alone is close to $800. This shows the importance of energy conservation measures. If incandescent lightbulbs were used instead of fluorescent tubes, the lighting costs would be four times as much since incandescent lamps use four times as much power for the same amount of light produced.

Recalculate the electric bill for Sweis hall in the CHE Department.
Try to provide an estimate of the electric bill for the whole University of Jordan campus and compare it to the actual bill of about $11 million.

Energy Conversion Efficiencies

- Definition

$$\text{Efficiency} = \eta = \frac{\text{Desired output}}{\text{Required input}}$$

- Efficiency of a water heater

$$\eta = \frac{\text{Energy delivered to the house by hot water}}{\text{Energy supplied to the water heater}}$$

Type	Efficiency
Gas, conventional	55%
Gas, high-efficiency	62%
Electric, conventional	90%
Electric, high-efficiency	94%

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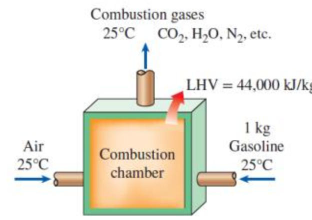
Heating Value of the Fuel

- The amount of heat released when a unit amount of fuel at room temperature is completely burned and the combustion products are cooled to the room temperature.
- Combustion equipment efficiency $\eta_{\text{comb.equip}}$

$$\eta = \frac{\text{Useful heat delivered by the combustion equipment}}{\text{Heating value of the fuel burned}}$$

Efficiencies of cars and jet engines are normally based on *lower heating values* since water normally leaves as a vapor in the exhaust gases, and it is not practical to try to recover the heat of vaporization. Efficiencies of furnaces, on the other hand, are based on *higher heating values*



Heating Value HV

- Lower LHV
- Higher HV

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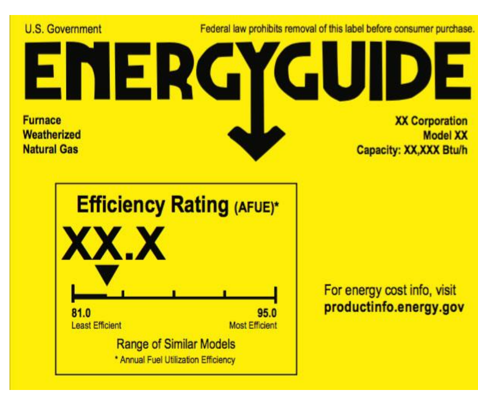
Space Heating Systems

- Annual fuel utilization efficiency (AFUE)
  - Accounts for the combustion equipment efficiency as well as other losses such as heat losses to unheated areas and start-up and cool-down losses.

AFUE

- Old heating systems < 60%
- New heating systems ~85%
- High efficiency furnaces >96%



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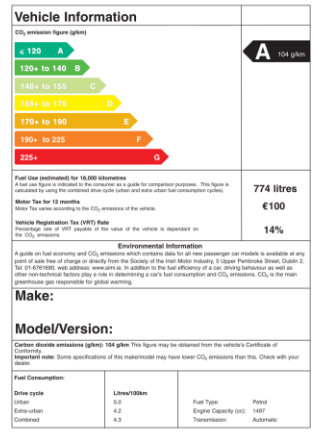
Car Engine Efficiency

- The work output is understood to be the power delivered by the crankshaft.

$$\eta = \frac{\text{Power delivered by the crank shaft}}{\text{Heating value of the fuel burned}}$$

Car Efficiency

- Gasoline automotive ~25-30%
- Diesel engines ~35-40%



Cars, CO_2 emission in g/km						
A	B	C	D	E	F	G
<100	<120	<140	<160	<200	<250	>250

Power Plant Efficiency

- A generator is a device that converts mechanical energy to electrical energy.
  - Generator efficiency is the ratio of the electrical power output to the mechanical power input.
- The thermal efficiency of a power plant
  - The ratio of the net shaft work output of the turbine to the heat input to the working fluid.
- Overall efficiency for the power plant is the ratio of the net electrical power output to the rate of fuel energy input

$$\eta_{\text{overall}} = \eta_{\text{comb.equip}}\eta_{\text{thermal}}\eta_{\text{generator}} = \frac{\dot{W}_{\text{net,electric}}}{HHV \times \dot{m}_{\text{fuel}}}$$

Thermal efficiency of power generation

Type of power plant	Efficiency %
Open cycle gas turbine	25 - 35
sub-critical coal	30 - 38
supercritical coal	35 - 45
solar thermal	32 - 38
nuclear	32 - 36
gas turbine combined cycle	45 - 60

Lighting Efficiency and Efficacy

- The efficiency for the conversion of electricity to light is the ratio of the energy converted to light to the electrical energy consumed.
- **Lighting efficacy** is the *amount of light output in lumens per W of electricity consumed.*

TABLE 2–1
The efficacy of different lighting systems

Type of lighting	Efficacy, lumens/W
Combustion	
Candle	0.3
Kerosene lamp	1–2
Incandescent	
Ordinary	6–20
Halogen	15–35
Fluorescent	
Compact	40–87
Tube	60–120
High-intensity discharge	
Mercury vapor	40–60
Metal halide	65–118
High-pressure sodium	85–140
Low-pressure sodium	70–200
Solid-State	
LED	20–160
OLED	15–60
Theoretical limit	300*

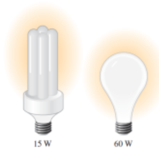


FIGURE 2–55
A 15-W compact fluorescent lamp provides as much light as a 60-W incandescent lamp.

***This value depends on the spectral distribution of the assumed ideal light source. For white light sources, the upper limit is about 300 lm/W for metal halide, 350 lm/W for fluorescents, and 400 lm/W for LEDs. Spectral maximum occurs at a wavelength of 555 nm (green) with a light output of 683 lm/W.**

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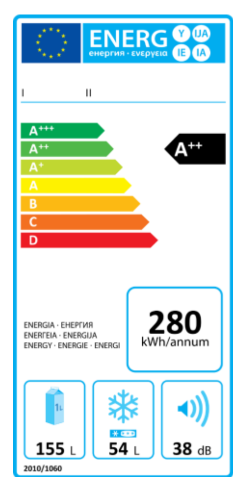
European Union Energy Label

https://en.wikipedia.org/wiki/European_Union_energy_label

Compulsory reading



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Self-Read

- Spring work
- Work Done on Elastic Solid Bars
- Work Associated with the Stretching of a Liquid Film
- Work Done to Raise or to Accelerate a Body

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