LECTURE # 4

Chapter 2 (Session #1):

Energy, Energy Transfer and General Energy Analysis

CHAPTER 2

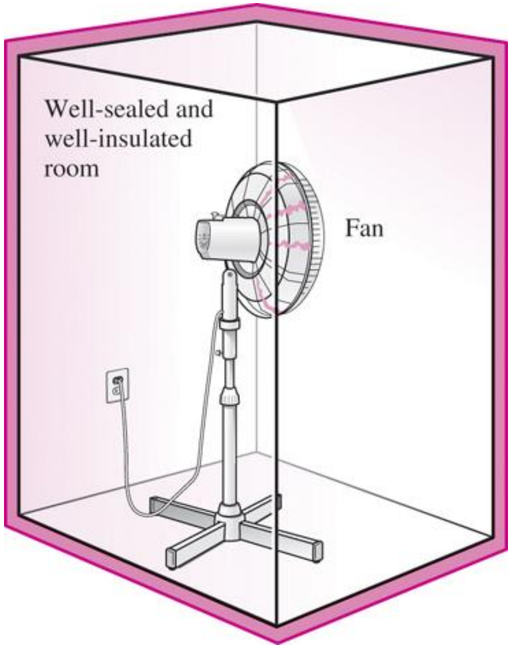
ENERGY, ENERGY TRANSFER & GENERAL ENERGY ANALYSIS

CHAPTER 2: Outcomes

- Understand Concept of Energy & define its various forms
- Define the concepts of "Heat" and "Work"
- State the First Law of Thermodynamics and identify means of energy transfer to and from a system
- Quantify the energy transferred by a flowing fluid across the control surface of an open system
- Define energy conversion efficiency
- Understand the impact of energy on the environment

Introduction – Understanding of the First Law

- First Law: Energy is conserved
  - The entire room (including the air and the fan) is an adiabatic closed system since the room is well-sealed and well-insulated, the only energy interaction involved is the electrical energy crossing the system boundary and entering the room.
- Total energy of the system will increase with time.



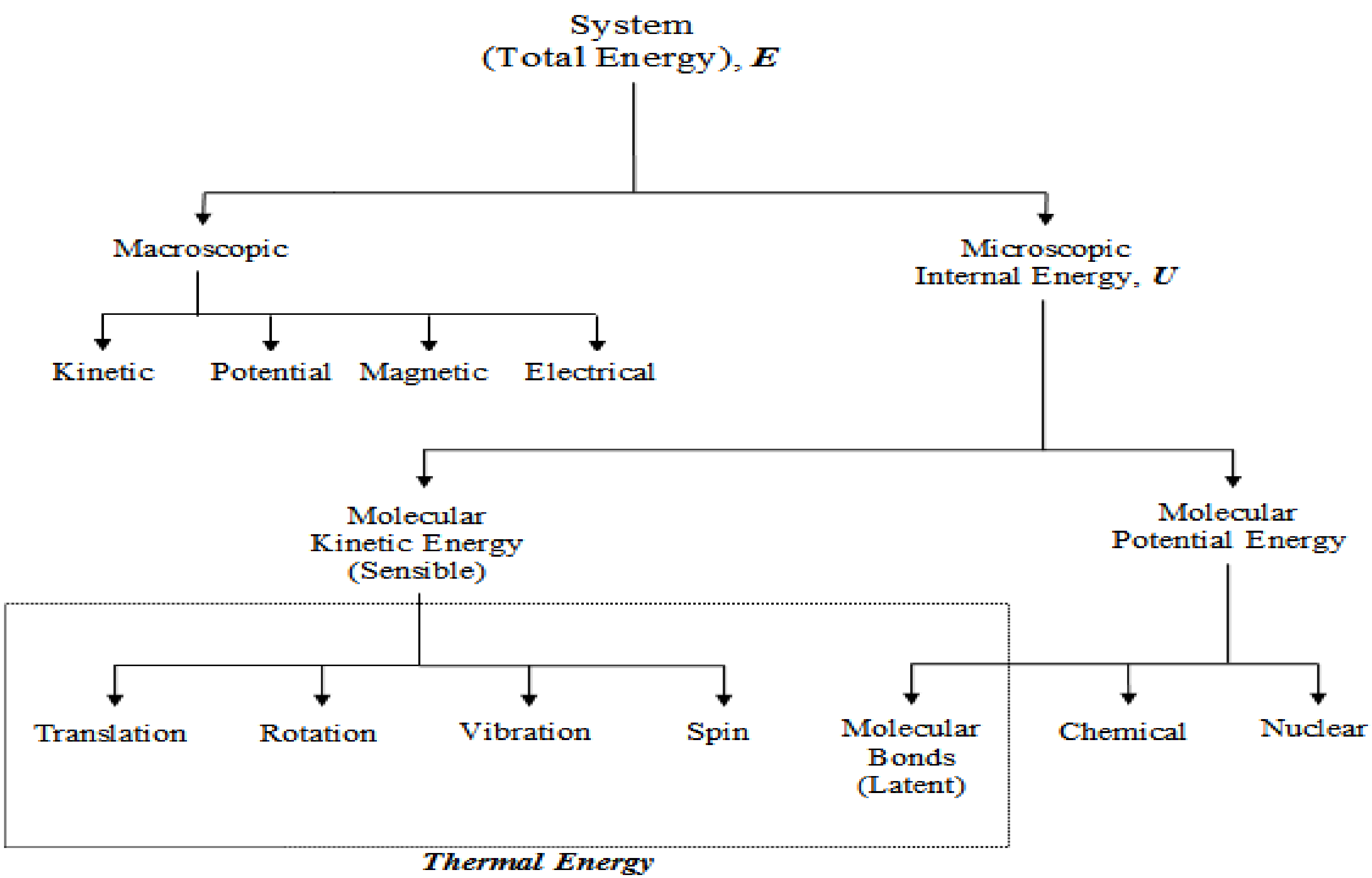
A fan running in a well-sealed and well-insulated room will raise the temperature of air in the room

Introduction – Understanding of the First Law

- What if we replace the fan with a refrigerator?
- What if the refrigerator door was closed?

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

Forms of Energy



Internal Energy

- Sum of all “microscopic” forms of energy
  - “Sensible” energy (Translation, rotation and vibration of molecules)
  - “Latent” energy (binding forces between molecules -- phase change process)
  - “Chemical” energy -- (bonds between atoms in a molecule)
  - “Nuclear” energy -- (bonds between nucleons within the nucleus of the atom)

Forms of Energy

- **Total Energy of the system, E (kJ)**
  - Extensive property
  - Energy per unit mass: $e = E/m$ (kJ/kg)
- **$E = U + KE + PE$**
  - U = Internal Energy (kJ)
  - KE = Kinetic energy = $m \mathbb{V}^2/2$ (kJ)
  - PE = Potential energy = $m\, g\, z$ (kJ)
    - g = gravitational acceleration; z = elevation of center of gravity w.r.t. arbitrary datum

Total Energy Per Unit Mass

- **e = u + ke + pe (kJ/kg)**
  - u = U/m = internal energy per unit mass (specific internal energy)
  - ke = $\mathbb{V}^2/2$ = kinetic energy per unit mass
  - pe = g z = potential energy per unit mass

Questions

- What is the difference between KE & "sensible" internal energy?
  - Bulk versus random motion
  - What is the effect of the reference frame?
- Which is larger $u_{gas\ phase}$ or $u_{liquid\ phase}$?

Energy Interactions with Surroundings

- The total energy of a system is the energy *"contained"* or *"stored"* in a system
- **How can we change the total energy of the system?**
  - Energy interactions with the surroundings
  - Energy transfer is recognized at the system boundary as it crosses that boundary.
  - Energy transfer represents the energy gained or lost by a system during a process.

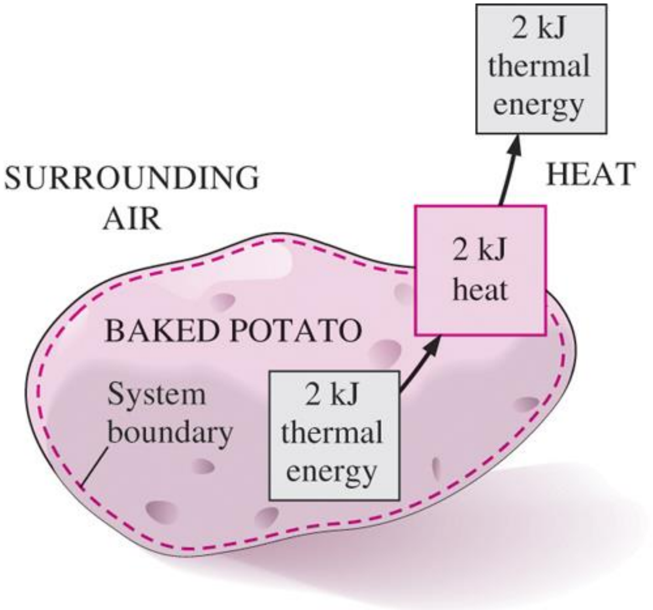
Energy Interactions with Surroundings

- Forms of energy interactions between system and surroundings
  - **Heat Transfer** (requires finite ΔT)
  - **Work** (e.g. compressing a gas in a cylinder)
  - **Mass** crossing the boundary (open systems)
  - For closed system energy transfer occurs only as heat and/or work
  - Heat Transfer & Work are **not** properties since they are "path dependent"

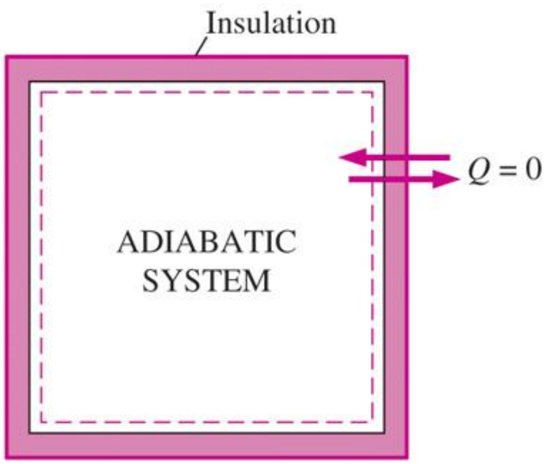
Heat

- **HEAT:** Energy transferred, without transfer of mass, across a boundary of a system because of a temperature difference between the system and surroundings
  - Q_{12} (or simply "Q") is amount of heat transfer during process between state "1" and state "2" [kJ]
  - **Note: Q_{12} is not a property** -- does not have a unique value at each equilibrium state -- associated with a process rather than a state
  - Processes or systems that do not involve heat transfer are called **"adiabatic"**

Energy Transfer as Heat



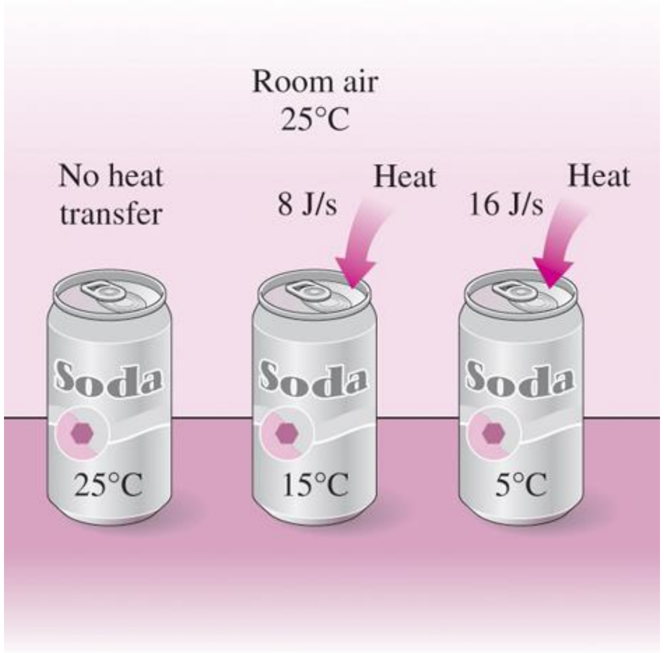
Energy is recognized as heat transfer only as it crosses the system boundary.



During an adiabatic process, a system exchanges no heat with its surroundings.

Energy Transfer as Heat

- Amount of heat transferred during a process is denoted by (Q) [units?]
- The rate of heat transfer is the amount of heat transferred per unit time and is denoted by ($\dot{Q}$) [units?]
  - Temperature difference is the driving potential for heat transfer. The larger the temperature difference, the higher is the rate of heat transfer.



1 joule (J) = 1 (N.m) = 1 (kg m^2/s^2)

1 (J/s) = 1 watt (W) = 1 N.m/s

Energy Transfer as Heat

- Amount of heat transfer when heat transfer rate changes with time

$$Q = \int_{t_1}^{t_2} \dot{Q}\, dt \qquad (\text{kJ})$$

- Amount of heat transfer when heat transfer rate is constant

$$Q = \dot{Q}\ \Delta t \qquad (\text{kJ})$$

Work

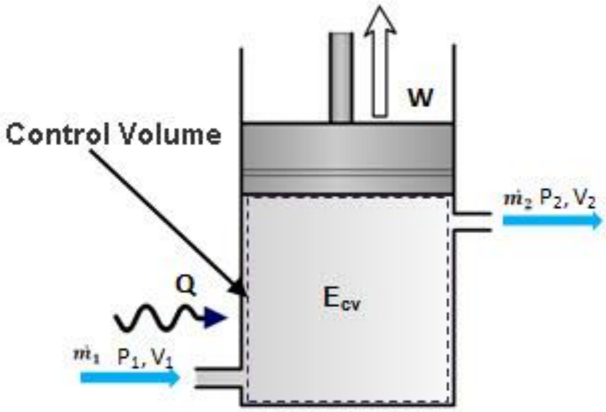
- **Work:** Energy transferred, without transfer of mass, across a boundary of a system because of an intensive property difference other than temperature that exists between the system and surroundings.
  - W_{12} (or simply "W") is amount of work done during process between state "1" and state "2" [kJ]
  - **Note: W_{12} is not a property** -- does not have a unique value at each equilibrium state -- associated with a process rather than a state

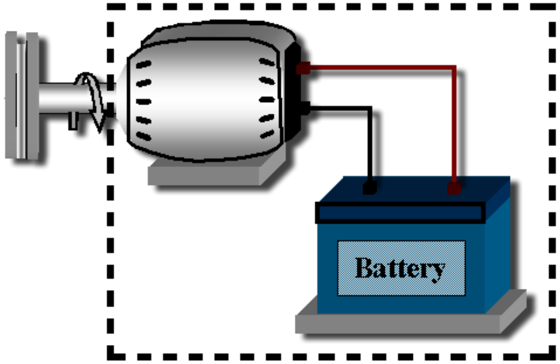
Energy Transfer as Work

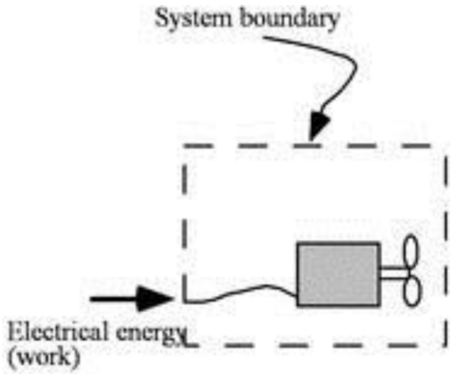
- Usual intensive property difference encountered in engineering systems is pressure
- Pressure difference gives rise to a force; action of force through a distance is **"Mechanical Work"**
- **Work:** The energy transfer associated with a force acting through a distance.

Energy Transfer as Work

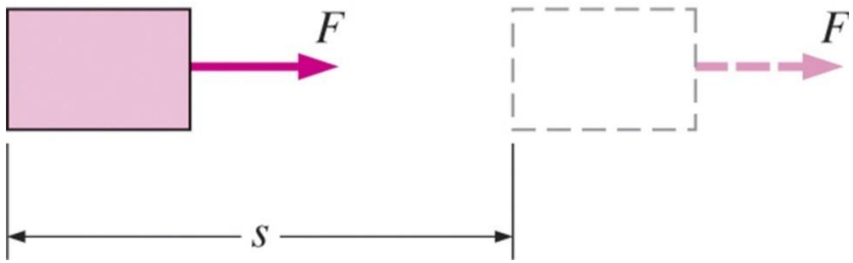
- **A moving piston, a rotating shaft,** and **an electric wire crossing the system boundaries** are all associated with work interactions

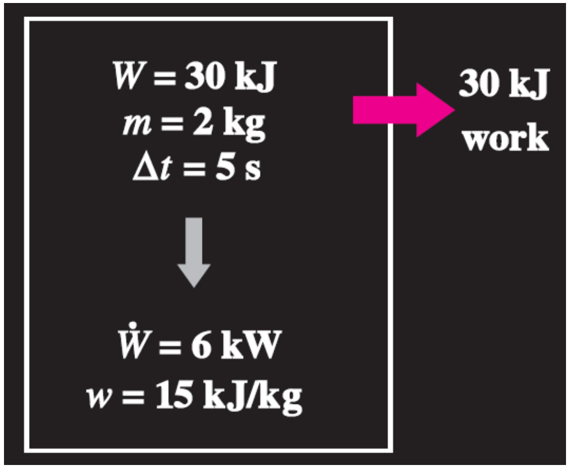






Energy Transfer as Work





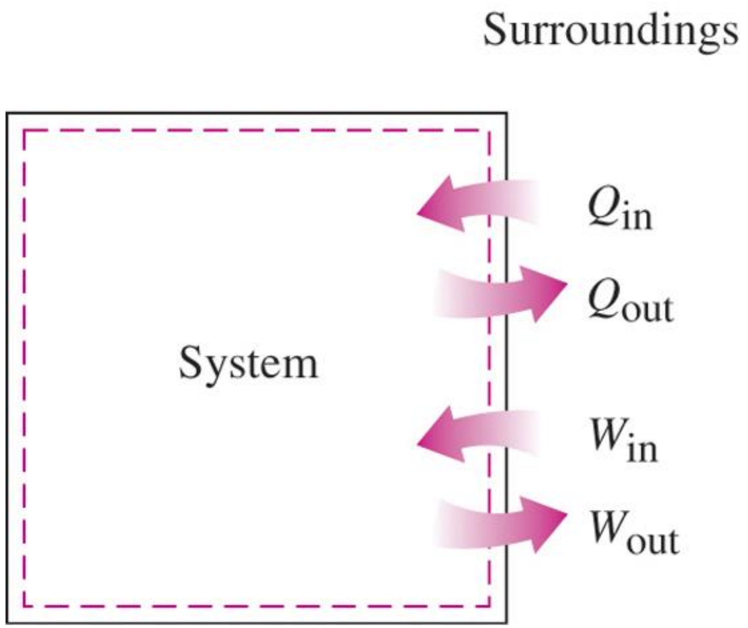
The work done is proportional to the force applied (*F*) and the distance traveled (*s*). [1J = 1 N.m]

Power is the work done per unit time (kW)

Formal Sign Convention

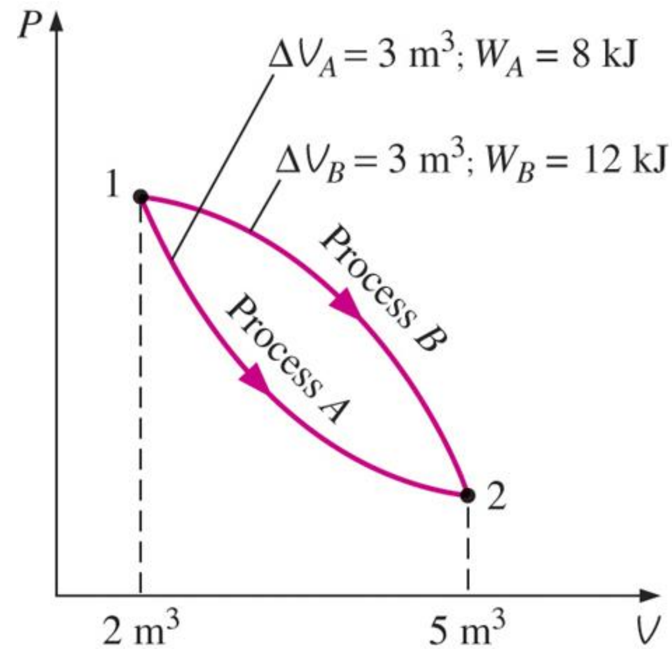
- Heat added to the system is positive
- Heat rejected from the system is negative
- Work done by the system is positive
- Work done on the system is negative

Alternative to sign convention is to use the subscripts ***in*** and ***out*** to indicate direction of energy transfer and assign a numerical value. This is the approach used in this text.



Heat & Work

- Both heat & work are recognized as they cross the boundaries of a system; i.e. both are *boundary* phenomena.
- Systems possess energy, but not heat or work.
- Both are associated with a *process*, not a state.
- Unlike properties, heat or work has no meaning at a state.
- Both are *path functions* (i.e., their magnitudes depend on the path followed during a process as well as the end states).



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

LECTURE # 5

Chapter 2 (Session #2):

Energy, Energy Transfer and General Energy Analysis

"Point" vs. "Path" Functions

- Properties are point functions -- they have exact differentials (d)
- Heat & Work are path functions -- they have inexact differentials (δ)

$$\int_1^2 dV = V_2 - V_1 = \Delta V$$

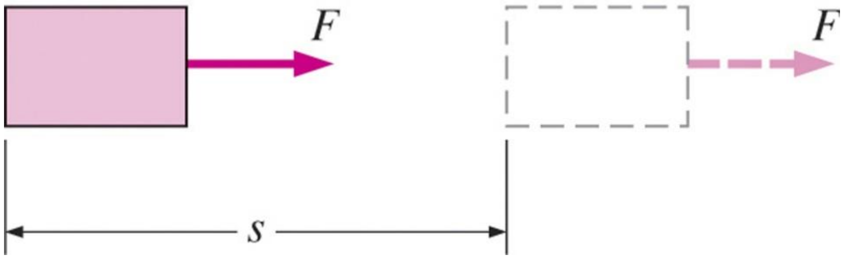
$$\int_1^2 \delta W = W_{12} \qquad (not\ \Delta W)$$

- $(\Delta V_{12})_A = (\Delta V_{12})_B$
- $(\Delta P_{12})_A = (\Delta P_{12})_B$

- $(W_{12})_A \neq (W_{12})_B$
- $(Q_{12})_A \neq (Q_{12})_B$

Mechanical Forms of Work

- There are two requirements for a work interaction between a system and its surroundings to exist:
  - there must be a ***force*** acting on the boundary.
  - the boundary must ***move***.



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

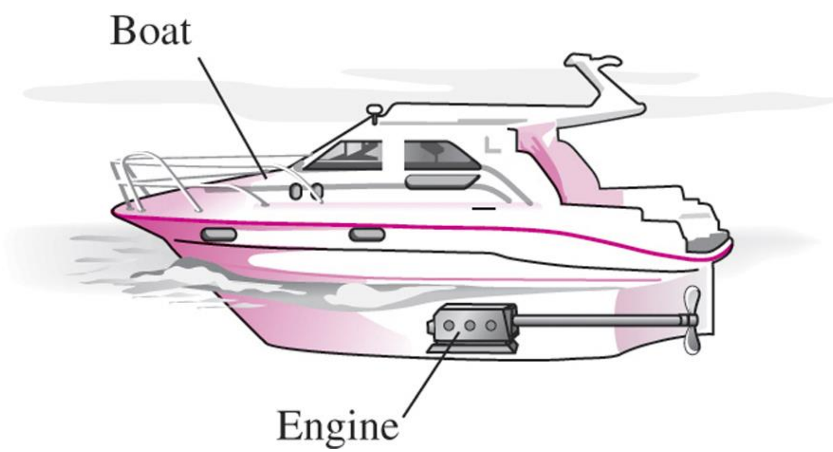
Work = Force × Distance

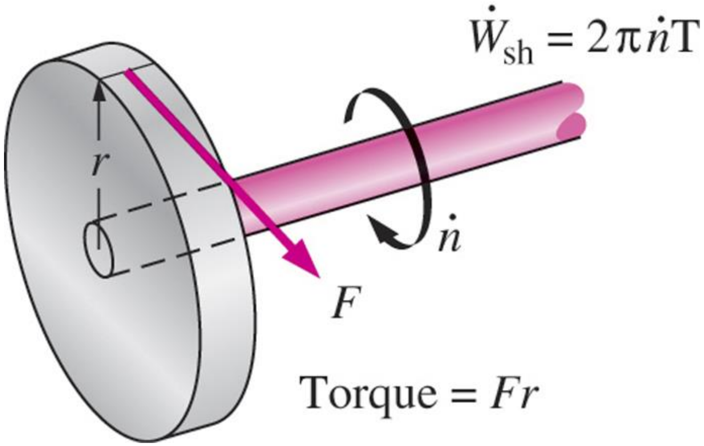
$$W = Fs \qquad \text{(kJ)}$$

When force is not constant

$$W = \int_1^2 F\,ds \qquad \text{(kJ)}$$

Shaft Work





Energy transmission through rotating shafts is commonly encountered in practice.

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

Shaft Work

- A force *F* acting through a moment arm *r* generates a torque T

$$\mathrm{T} = Fr \quad \rightarrow \quad F = \frac{\mathrm{T}}{r}$$

- As shaft rotates, this force acts through a distance, s. $s = (2\pi r)n$

- Shaft Work: $$W_{sh} = Fs = \left(\frac{\mathrm{T}}{r}\right)(2\pi rn) = 2\pi n\mathrm{T} \qquad \mathrm{(kJ)}$$

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

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

Spring Work

- When the length of a spring changes by a differential amount ***dx*** under the influence of a force ***F***, the work done is:

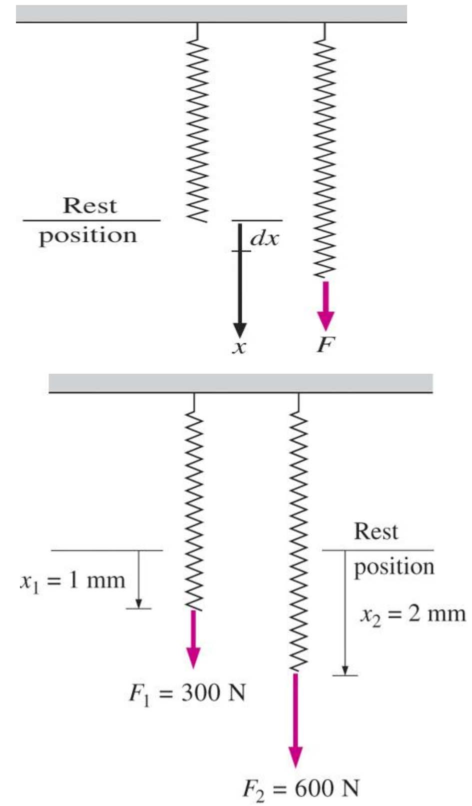
$$\delta W_{\text{spring}} = F\,dx$$

- For linear elastic springs, the displacement *x* is proportional to the force applied

- $F = k\,x$ (N); k = spring constant (N/m)
- Substituting & integrating yields:

$$\boxed{W_{\text{spring}} = \tfrac{1}{2}k\left(x_2^2 - x_1^2\right)} \quad \text{(J)}$$

- x_1 and x_2 are the initial and final displacements

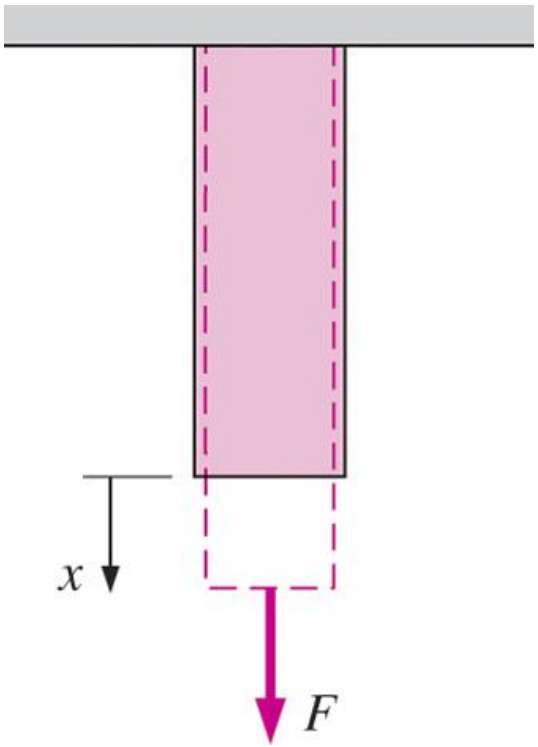


The displacement of a linear spring doubles when the force is doubled.

Work Done on Elastic Solid Bars

- Elastic solid bars behave as springs under the influence of a force

$$W_{elastic} = \int_1^2 F\,dx = \int_1^2 \sigma_n A\,dx \qquad \text{(kJ)}$$



Other Forms of Mechanical Work

- Stretching of liquid films
- Raising of a body in gravitational field
- Acceleration of a body

Non-Mechanical Forms of Work

- **Electrical work**: The generalized force is the *voltage* (the electrical potential) and the generalized displacement is the *electrical charge.*
- **Magnetic work**: The generalized force is the *magnetic field strength* and the generalized displacement is the total *magnetic dipole moment.*
- **Electrical polarization work**: The generalized force is the *electric field strength* and the generalized displacement is the *polarization of the medium.*

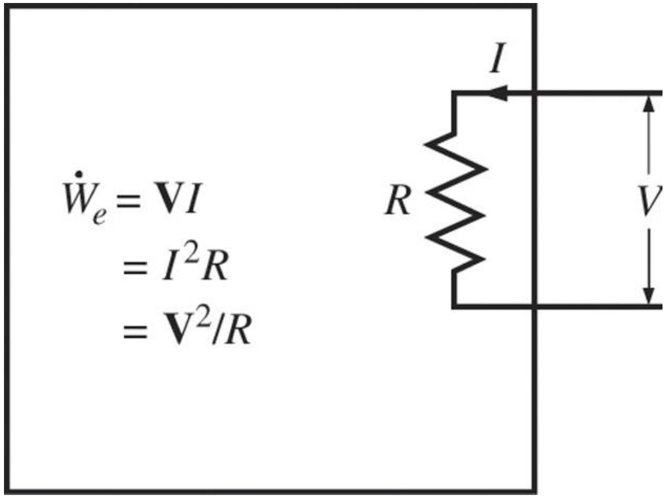
Electrical Work

- Electrical Work $W_e = \mathbf{V}N$ (kJ)
  - V = Applied Voltage
  - N = Number of coulombs of electrons moved through potential difference
- Electrical Power $\dot{W}_e = \mathbf{V}I$ (W)
- When *V* & *I* are constant

$$W_e = \mathbf{V}I\ \Delta t \qquad \text{(kJ)}$$

- When Potential difference and current change with time

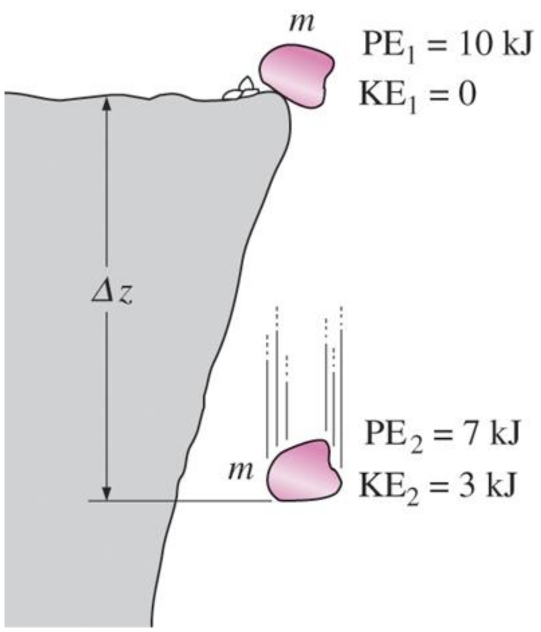
$$W_e = \int_1^2 \mathbf{V}I\,dt \qquad \text{(kJ)}$$



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

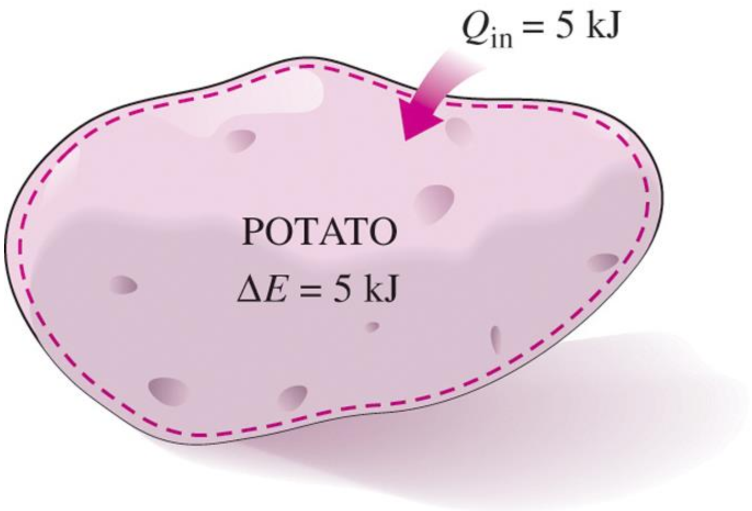
The First Law of Thermodynamics

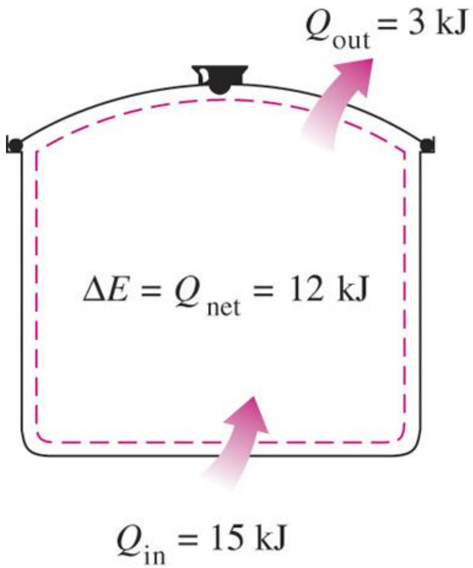
- **The *first law of thermodynamics* *(the conservation of energy principle)*** provides a systematic quantitative basis for studying the relationships among the various forms of energy for a system and energy interactions between a system and its surroundings.



Energy cannot be created or destroyed; it can only change forms.

The First Law of Thermodynamics

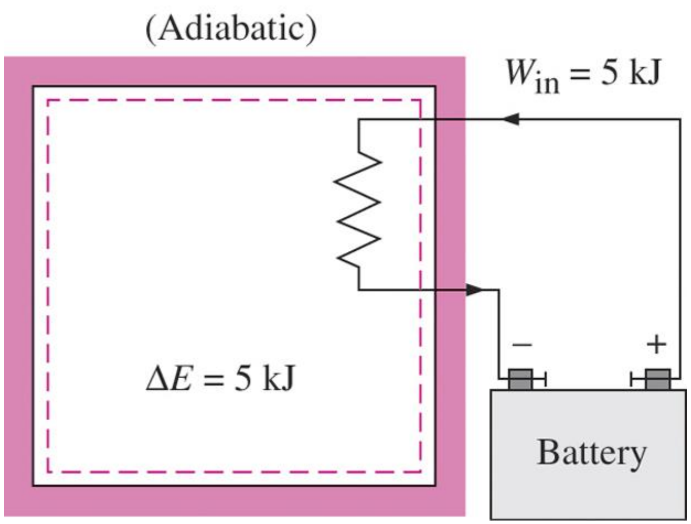


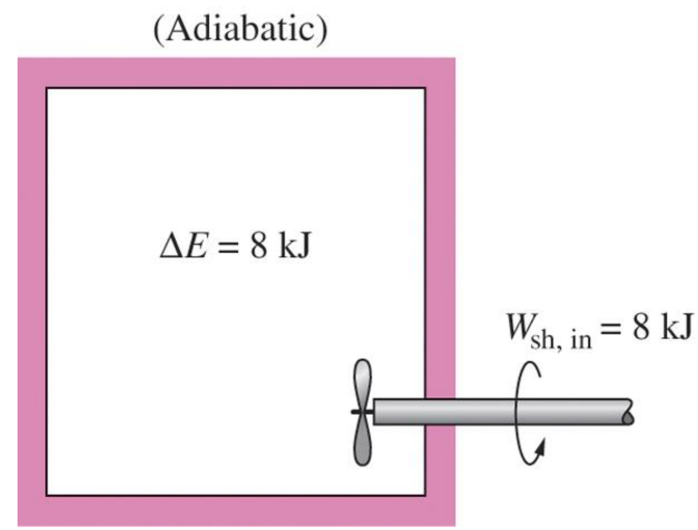


The increase in the energy of a potato in an oven is equal to the amount of heat transferred to it.

In the absence of any work interactions, the energy change of a closed system is equal to the net heat transfer.

The First Law of Thermodynamics





The work (electrical) done on an adiabatic system is equal to the increase in the energy of the system.

The work (shaft) done on an adiabatic system is equal to the increase in the energy of the system.

Energy Change of a System ΔE_{system}

(Energy Change) = (Energy at final state) - (Energy at initial state)

$$\Delta E_{\text{system}} = E_{\text{final}} - E_{\text{initial}} = E_2 - E_1$$

$$\Delta E = \Delta U + \Delta \text{KE} + \Delta \text{PE}$$

- **Internal, Kinetic, and Potential Energy of the system may change**

Energy Change of a System ΔE_{system}

- Internal, Kinetic, and Potential energy changes

$$\Delta U = m(u_2 - u_1)$$

$$\Delta KE = \frac{1}{2} m(V_2^2 - V_1^2)$$

$$\Delta PE = mg(z_2 - z_1)$$

Stationary Systems

$$z_1 = z_2 \rightarrow \Delta PE = 0$$

$$V_1 = V_2 \rightarrow \Delta KE = 0$$

$$\Delta E = \Delta U$$

Energy Balance (The First Law)

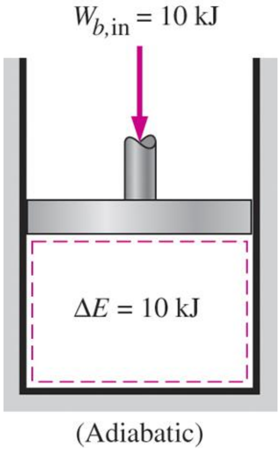
- *The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process.*

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

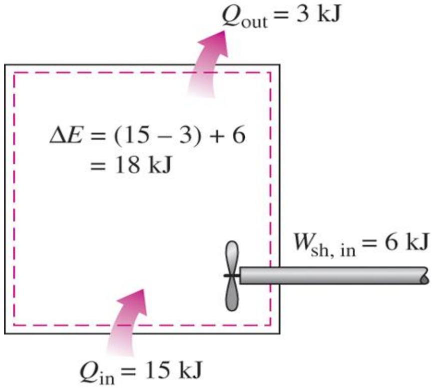
$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

Energy Balance
(Closed System Undergoing a Process)

- For a **closed system**, energy exchange with the surroundings occurs only as either work or heat



The work done on an adiabatic system is equal to the increase in the energy of the system.

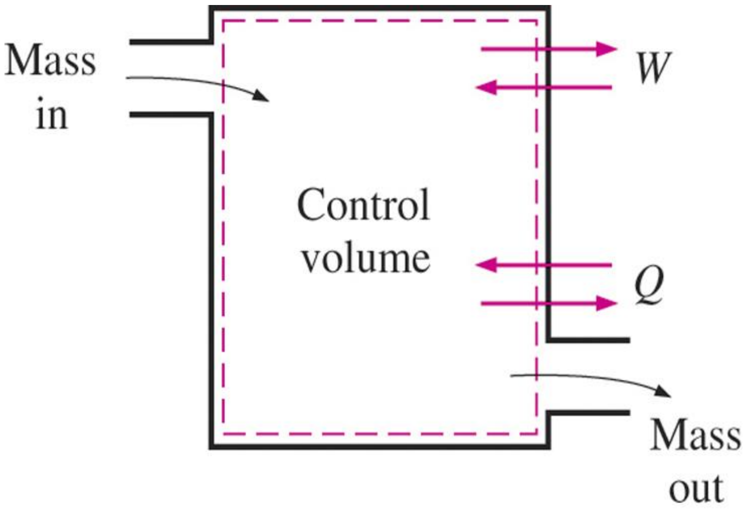


The energy change of a system during a process is equal to the *net* work and heat transfer between the system and its surroundings.

$$E_{in} - E_{out} = \underbrace{(Q_{in} - Q_{out})}_{\text{Heat Transfer}} + \underbrace{(W_{in} - W_{out})}_{\text{Work Transfer}} = \Delta E_{system}$$

Energy Transfer for Open Systems

The energy content of an open system (control volume) can be changed by mass flow across the boundary as well as heat and work interactions.



$$E_{in} - E_{out} = \underbrace{(Q_{in} - Q_{out})}_{\text{Heat Transfer}} + \underbrace{(W_{in} - W_{out})}_{\text{Work Transfer}} + \underbrace{(E_{mass,in} - E_{mass,out})}_{\text{Mass Transfer}} = \Delta E_{system}$$

Energy Balance (The First Law)

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

- Energy balance can be applied on a per unit time basis, i.e. as a rate equation

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

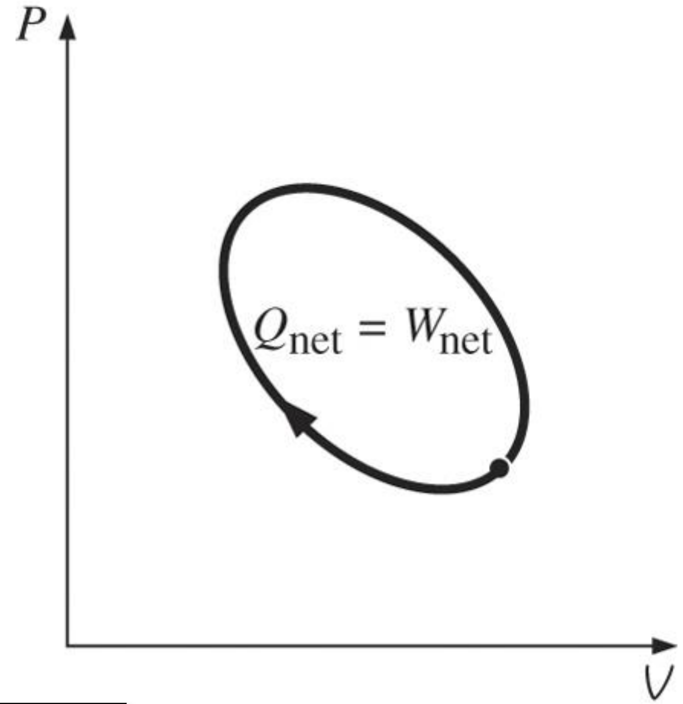
Energy Balance
Closed System Undergoing a Cycle

- A cycle is a sequence of processes that return the system to its initial state; therefore: ΔE_{system} = zero

$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = \text{zero}$$

i.e. $W_{net} = Q_{net}$

$W_{net} = (W_{out} - W_{in})$ and $Q_{net} = (Q_{in} - Q_{out})$



- On a rate basis:

$$\dot{W}_{net,out} = \dot{Q}_{net,in} \qquad \text{(for a cycle)}$$

Energy Conversion Efficiencies

- Performance is measured by comparing the desired output to the required input
- Examples (processes):
  - Motor: $\eta_{motor} = \dfrac{\text{Mechanical Power Output}}{\text{Electric Power Input}}$ (Units??)
  - Pump: $\eta_{pump} = \dfrac{\text{mechanical energy increase of the fluid}}{\text{mechanical energy input}}$
  - Turbine: $\eta_{turbine} = \dfrac{\text{mechanical energy output}}{\text{mechanical energy decrease of the fluid}}$

Energy Conversion Efficiencies

- Examples: Systems operating continuously (in cycles)
- Power Plants:
  - $$\text{Overall Thermal Efficiency} = \frac{\textbf{Net}\text{ Electric Power Output}}{\text{Thermal Power Input}}$$

(Units??)

- Refrigerators:
  - $$\text{Coefficient of Performance} = \frac{\text{heat removal rate from refrigerated space}}{\text{Electric Power Input}}$$

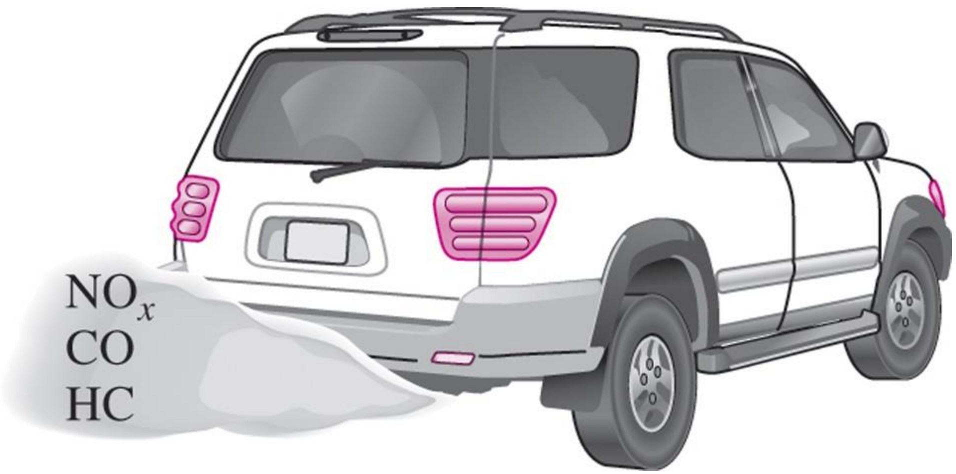
Energy and the Environment

- The conversion of energy from one form to another often affects the environment and the air we breathe in many ways, and thus the study of energy is not complete without considering its impact on the environment.

Energy conversion processes are often accompanied by environmental pollution.

Energy and the Environment

- Pollutants emitted during the combustion of fossil fuels are responsible for **smog**, **acid rain**, and **global warming**.
- The environmental pollution has reached such high levels that it became a serious threat to **vegetation**, **wild life**, and **human health**.



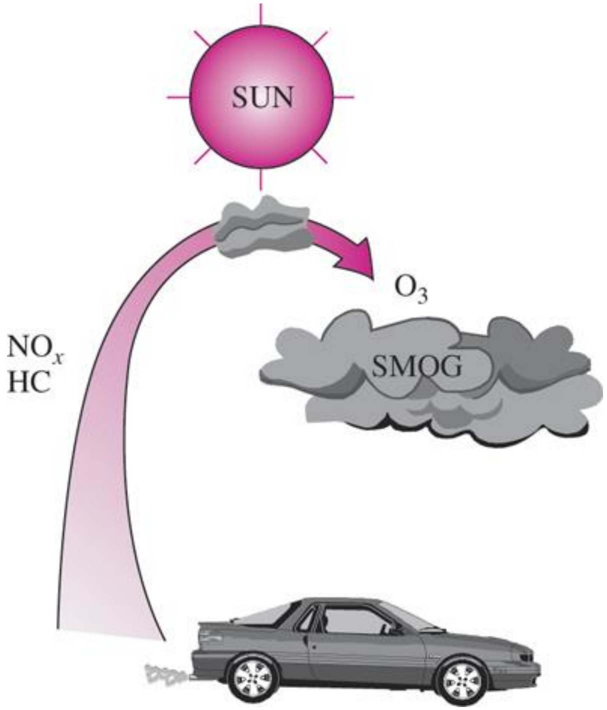
Motor vehicles are the largest source of air pollution.

Ozone and Smog

- **Smog**: Made up mostly of ground-level ozone (O_3), but it also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOCs) such as benzene, butane, and other hydrocarbons.
- **Hydrocarbons** and **nitrogen oxides** react in the presence of sunlight on hot calm days to form ground-level ozone.
- **Ozone** irritates eyes and damages the air sacs in the lungs where oxygen and carbon dioxide are exchanged, causing eventual hardening of this soft and spongy tissue.
- It also causes shortness of breath, wheezing, fatigue, headaches, and nausea, and aggravates respiratory problems such as asthma.

Ozone and Smog

- The other serious pollutant in smog is **carbon monoxide**, which is a colorless, odorless, poisonous gas.
- It is mostly emitted by motor vehicles.
- It deprives the body's organs from getting enough oxygen by binding with the red blood cells that would otherwise carry oxygen. It is fatal at high levels.
- Suspended particulate matter such as dust and soot are emitted by vehicles and industrial facilities. Such particles irritate the eyes and the lungs.



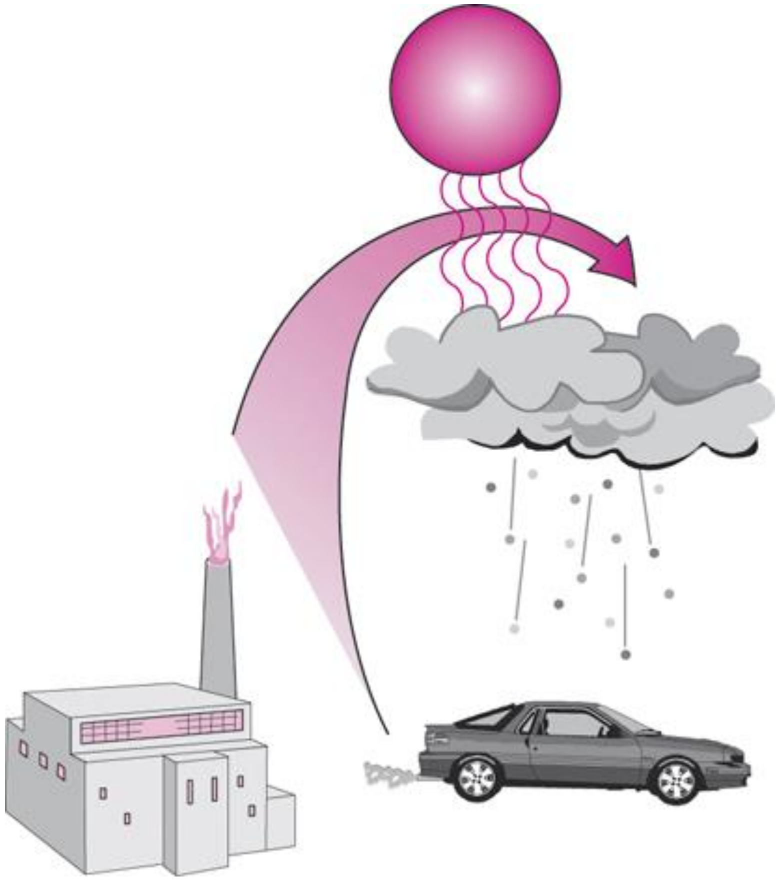
Ground-level ozone forms when HC and NO_x react in the presence of sunlight in hot calm days.

Acid Rain

- The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2), which is an air pollutant.
- The main source of SO_2 is the electric power plants that burn high-sulfur coal.
- Motor vehicles also contribute to SO_2 emissions since gasoline and diesel fuel also contain small amounts of sulfur.

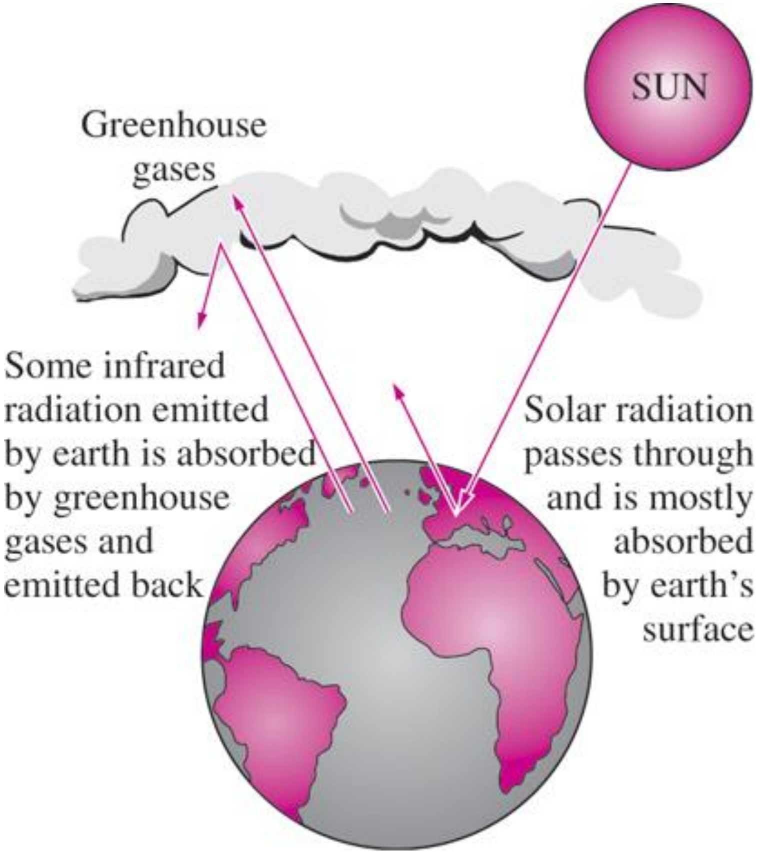
Acid Rain

- The sulfur oxides and nitric oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight to form sulfuric and nitric acids.
- The acids formed usually dissolve in the suspended water droplets in clouds or fog.
- These acid-laden droplets, which can be as acidic as lemon juice, are washed from the air on to the soil by rain or snow. This is known as **acid rain**.



The Greenhouse Effect: Global Warming

- **Greenhouse effect**: Glass allows the solar radiation to enter freely but blocks the infrared radiation emitted by the interior surfaces. This causes a rise in the interior temperature as a result of the thermal energy buildup in a space (i.e., car).
- The surface of the earth, which warms up during the day as a result of the absorption of solar energy, cools down at night by radiating part of its energy into deep space as infrared radiation.



The greenhouse effect on earth.

The Greenhouse Effect: Global Warming

- **Carbon dioxide (CO_2),** water vapor, and trace amounts of some other gases such as methane and nitrogen oxides act like a blanket and keep the earth warm at night by blocking the heat radiated from the earth. The result is **global warming**.
- These gases are called "**greenhouse gases**," with CO_2 being the primary component.
- CO_2 is produced by the burning of fossil fuels such as **coal, oil, and natural gas**.

The Greenhouse Effect: Global Warming

- **A 1995 report**: The earth has already warmed about **0.5°C** during the last century, and they estimate that the earth's temperature will rise another **2°C** by the year 2100.
- A rise of this magnitude can cause **severe changes in weather patterns.**

The average car produces several times its weight in CO_2 every year (it is driven 20,000 km a year, consumes 2300 liters of gasoline, and produces 2.5 kg of CO_2 per liter).

The Greenhouse Effect: Global Warming

- Improved energy efficiency, energy conservation, and using renewable energy sources help minimize global warming.

Renewable energies such as wind are called “green energy” since they emit no pollutants or greenhouse gases.

CHAPTER 2: Outcomes

- ✓ Understand Concept of Energy & define its various forms
- ✓ Define the concepts of "Heat" and "Work"
- ✓ State the First Law of Thermodynamics and identify means of energy transfer to and from a system
- ✓ Quantify the energy transferred by a flowing fluid across the control surface of an open system
- ✓ Define energy conversion efficiency
- ✓ Recognize environmental phenomena related to energy