Nano-materials for Energy conversion and storage

NAC 2401: Lecture 2

Energy: forms & types

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State

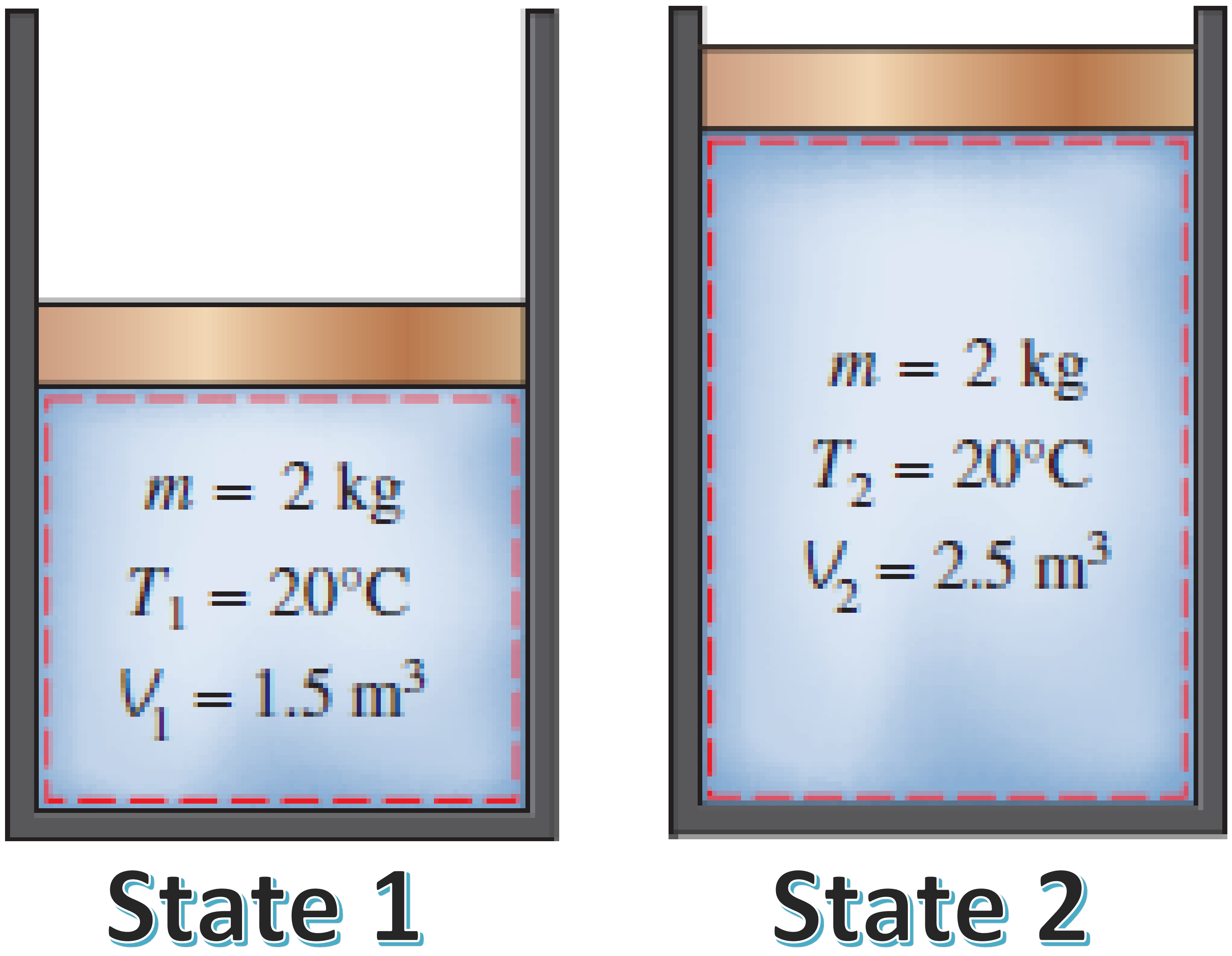
- is a **condition** describing a system at **equilibrium** when all properties (variables) (measured or calculated) throughout the entire system are fixed (unchanged).

- If the value of even **one** property changes, the state will change.

Property

observable characteristic of a system

- **External**: macroscopic velocities, or position coordinates in an external field.
- **Internal** (Intensive/extensive): P, V, m, etc., of all substances in the system.



m = 2 kg
T1 = 20°C
V1 = 1.5 m3
State 1
m = 2 kg
T2 = 20°C
V2 = 2.5 m3
State 2

Extensive/Intensive Properties

- **Extensive property (Functions):** functions which depend on the mass of the material or the system's size (e.g., total mass, total volumes, total momentum, Internal energy, Volume)
- **Intensive Property (Functions):** functions which are independent of the mass of the material (e.g., Pressure, Temperature, Density, Molar quantities).
  - Includes extensive properties per unit mass (specific properties), e.g., specific volume (v=V/m) and specific total energy (e = E/m).

Generally, **uppercase letters** are used to denote extensive properties (with mass *m* being a major exception), and **lowercase letters** are used for intensive properties (with pressure *P* and temperature *T* being the obvious exceptions).

Equilibrium A state of balance

- Driving forces (**potential**) are balanced in all directions within the system.

- No change in all **intensive** properties with time.

- Thermodynamics deals with **equilibrium** states.

- There are many types of equilibrium (thermal, mechanical, phase, chemical), and a system is not in thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied.

- **Thermal equilibrium** indicates keeping the temperature the same throughout the entire system, i.e., no driving force for heat flow.

- **Mechanical equilibrium** indicates no change in pressure at any point of the system with time.

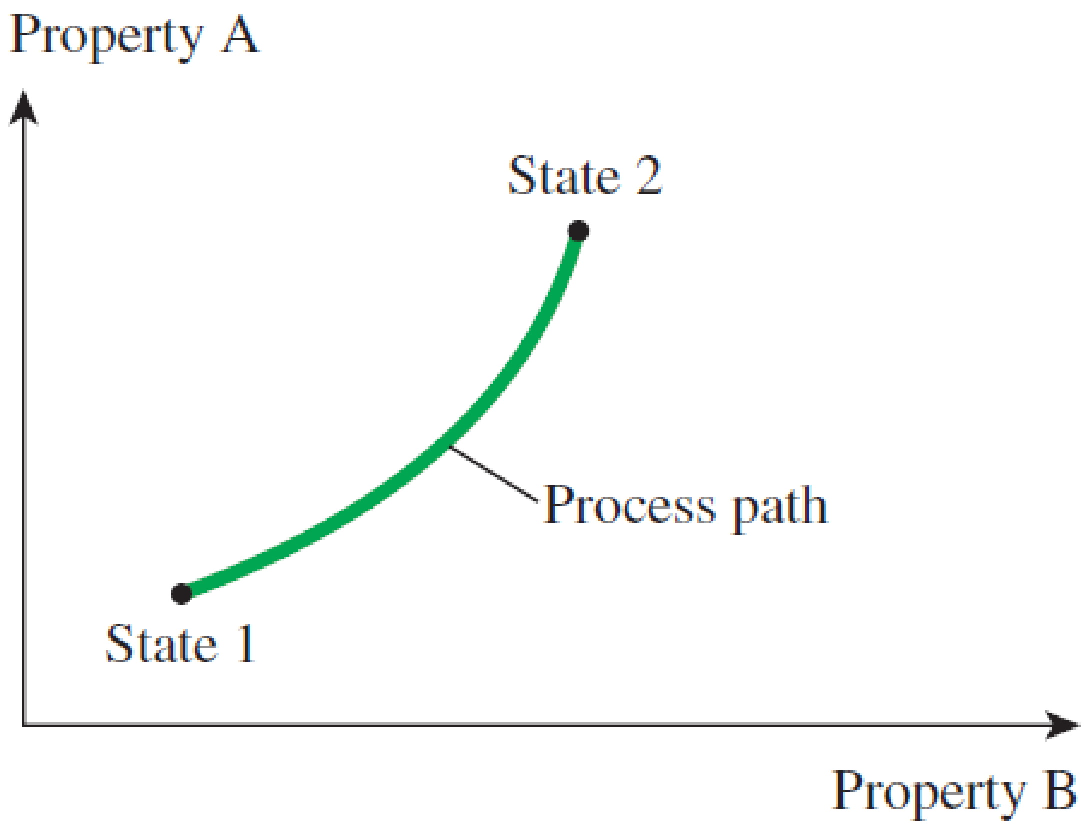
- **Phase equilibrium** (If a system involves two phases), indicates that the mass of each phase reaches an equilibrium level and stays there.

- **Chemical equilibrium** indicates no change in the chemical composition of the system with time, that is, no chemical reactions occur.

Process

Any change that a system undergoes from one **equilibrium** state to another

- The series of states through which a system passes during a process is called the path of the process.



Processes: Types

- The prefix **iso-** is often used to designate a process for which a particular property remains constant
- An **isothermal** process is a process during which the **temperature** T remains constant.
- An **isobaric** process is a process during which the **pressure** P remains constant.
- An **isochoric** (or **isometric**) process is a process during which the specific **volume** **v** remains constant.
- An **Isentropic** process is an internally reversible and adiabatic process. In such a process the **entropy** remains constant.

- **Batch process**: material is **neither** added to nor removed from the process during its operation.
- **A semi-batch process**: material may be added but product is not removed during the operation.
- **Steady-flow process**: a fluid flows through a control volume steadily and no intensive or extensive properties within the control volume change with time. The fluid properties can change from point to point within the control volume, but at any point, they remain constant during the entire process.
- **Unsteady-flow, or transient-flow process**: properties change within a control volume with time.

Cycle

$$\oint dU = 0$$

A system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle the initial and final states are identical.

- **"Steady"** implies no change with time. The opposite of steady is unsteady, or transient.
- **"Uniform"** implies no change with location over a specified region.

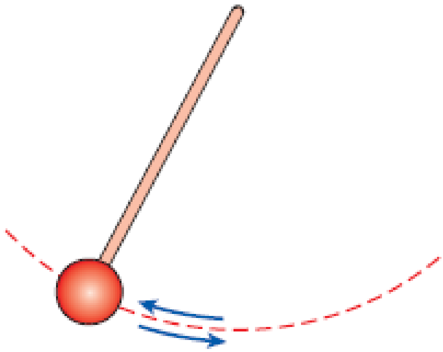
Reversible/irreversible processes

"Once a cup of hot coffee cools, it will not heat up by retrieving the heat it lost from the surroundings."

irreversible

Reversible

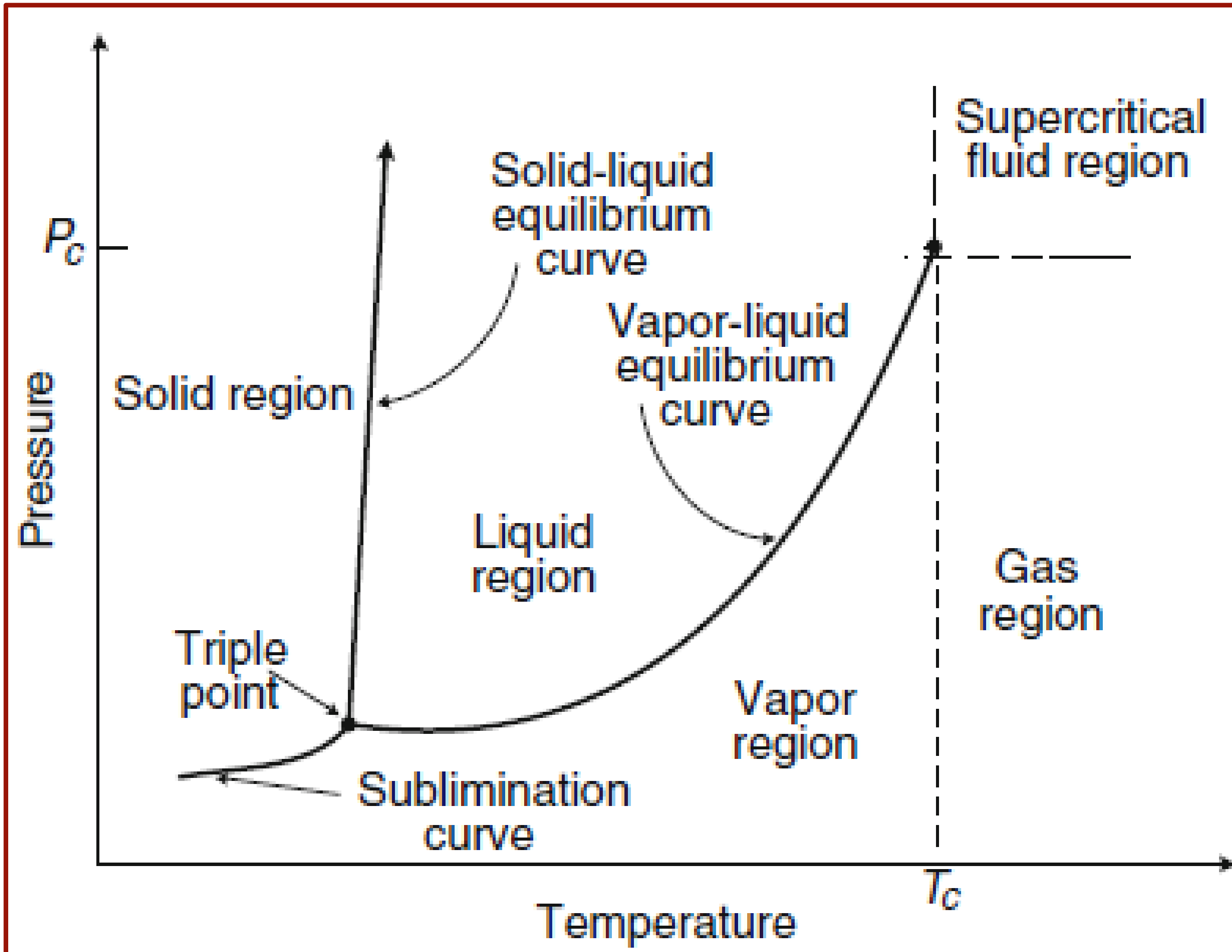
- "a process that can be reversed without leaving any trace on the surroundings".
- both the system and the surroundings are returned to their initial states at the end of the reverse process.
- This is possible only if the net heat and net work exchange between the system and the surroundings is zero for the combined (original and reverse) process.



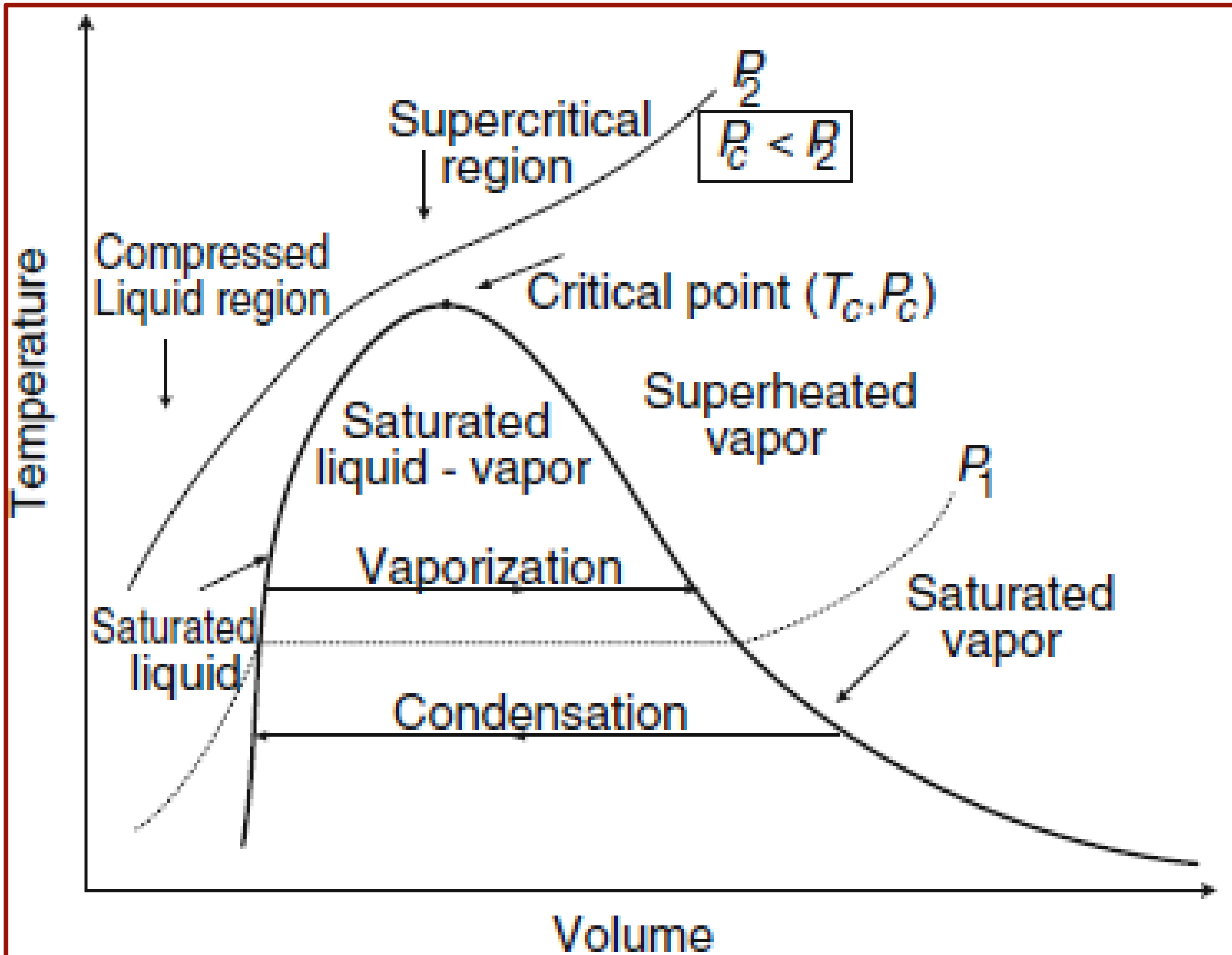
Frictionless pendulum

A system passes through a series of equilibrium states during a reversible process.

Phase diagram of a pure substance



Saturated Liquid & Saturated Vapor State



Steam Tables

Table 1.10 Saturated water in SI units

T (K)	P^{sat} (kPa)	V (cm^3/g)		U (kJ/kg)		Enthalpy H (kJ/kg)		Entropy S (kJ/kg K)	
		V_l	V_g	U_l	U_g	H_l	H_g	V_l	V_g
372.15	97.76	1.043	1730.0	414.7	2505.3	414.8	2674.4	1.2956	7.3675
373.15	101.33	1.044	1673.0	419.0	2506.5	419.1	2676.0	1.3069	7.3554
375.15	108.78	1.045	1565.5	427.4	2508.8	427.5	2679.1	1.3294	7.3315
377.15	116.68	1.047	1466.2	435.8	2511.1	435.9	2682.2	1.3518	7.3078
379.15	125.04	1.049	1374.2	444.3	2513.4	444.4	2685.3	1.3742	7.2845
381.15	133.90	1.050	1288.9	452.7	2515.7	452.9	2688.3	1.3964	7.2615
383.15	143.27	1.052	1209.9	461.2	2518.0	461.3	2691.3	1.4185	7.2388

Table 1.12 Superheated steam in SI units

T (°C)	V (cm^3/g)	U (kJ/kg)	H (kJ/kg)	S (kJ/kg K)	V (cm^3/g)	U (kJ/kg)	H (kJ/kg)	S (kJ/kg K)
	P = 1200 kPa, T^{sat} = 187.96°C				P = 1250 kPa, T^{sat} = 189.81°C			
Sat. liq.	1.139	797.1	798.4	2.2161	1.141	805.3	806.7	2.2338
Sat. vap.	163.20	2586.9	2782.7	6.5194	156.93	2588.0	2784.1	6.5050
200	169.23	2611.3	2814.4	6.5872	161.88	2608.9	2811.2	6.5630
220	178.80	2650.0	2864.5	6.6909	171.17	2648.0	2861.9	6.6680
240	187.95	2686.7	2912.2	6.7858	180.02	2685.1	2910.1	6.7637
260	196.79	2722.1	2958.2	6.8738	188.56	2720.8	2956.5	6.8523
280	205.40	2756.5	3003.0	6.9562	196.88	2755.4	3001.5	6.9353
300	213.85	2790.3	3046.9	7.0342	205.02	2789.3	3045.6	7.0136

Exercise

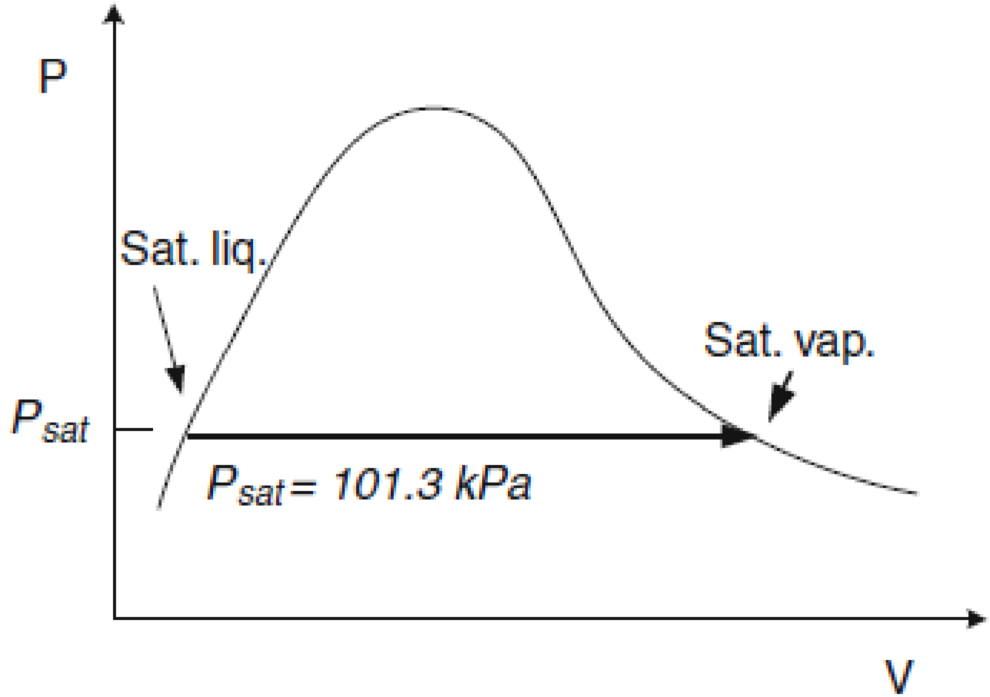
A mass of 22 kg of saturated liquid water at 101.3 kPa is evaporated completely at constant pressure and produced saturated vapor. Estimate the temperature of the vapor and amount of energy added to the water.

Solution

Table 1.10 Saturated water in SI units

T (K)	P^{sat} (kPa)	V (cm^3/g)		U (kJ/kg)		Enthalpy H (kJ/kg)		Entropy S (kJ/kg K)	
		V_l	V_g	U_l	U_g	H_l	H_g	V_l	V_g
372.15	97.76	1.043	1730.0	414.7	2505.3	414.8	2674.4	1.2956	7.3675
373.15	101.33	1.044	1673.0	419.0	2506.5	419.1	2676.0	1.3069	7.3554

$$P_{sat} = 101.3 \text{ kPa and } T_{sat} = 100^\circ C$$



$$H_{sat\ liq} = 419.1\ kJ/kg \qquad H_{sat\ vap} = 2676.0\ kJ/kg$$

$$\Delta H_{vap} = H_{sat\ vap} - H_{sat\ liq}$$
$$= (2676.0 - 419.1)\ kJ/kg = 2256.9\ kJ/kg$$

Total amount of heat added

$$= (2256.9\ kJ/kg)(22\ kg) = 49{,}651.8\ kJ$$

Saturated Liquid–Vapor Mixture

- The proportions of vapor and liquids phases in the saturated mixture is called the **quality** x, which is the ratio of mass of vapor to the total mass of the mixture.

$$x = \frac{\text{mass of vapor}}{\textbf{mass of mixture}}$$

Average values of specific volume, enthalpy, and internal energy of a saturated liquid–vapor mixture are estimated by:

$$V = (1 - x)\,V_{sat\ liq} + xV_{sat\ vap}$$

$$H = (1 - x)\,H_{sat\ liq} + xH_{sat\ vap}$$

$$U = (1 - x)\,U_{sat\ liq} + xU_{sat\ vap}$$

Exercise

A rigid tank contains 15 kg of saturated liquid and vapor water at 85°C. Only 2 kg of the water is in liquid state. Estimate the enthalpy of the saturated mixture and the volume of the tank.

Solution

From tables, saturated liquid–vapor water mixture at P_{sat} = 57.8 kPa and T_{sat} = 85°C

$$h_{sat\ vap} = 2652.0\ kJ/kg \qquad v_{vap} = 2828.8\ cm^3/g$$

$$h_{sat\ liq} = 355.9\ kJ/kg \qquad v_{liq} = 1.003\ cm^3/g$$

$$\text{Amount of liquid water} = 2\ kg$$

$$\text{Amount of vapor} = 15 - 2 = 13\ kg$$

$$x = \frac{\text{mass of vapor}}{\textbf{mass of mixture}} = \frac{13}{15} = 0.87$$

$$h_{mix} = (1 - x)\, h_{sat\ liq} + x h_{sat\ vap}$$

$$= (1 - 0.87)355.9\,\frac{\text{kJ}}{\text{kg}} + (0.87)2652.0\,\frac{\text{kJ}}{\text{kg}} = 2353.5\,\frac{\text{kJ}}{\text{kg}}$$

$$h_{sat\ vap} > h_{sat\ liq} > h_{mix}$$

$$v_{mix} = (1 - x)\, v_{sat\ liq} + x v_{sat\ vap}$$

$$= (1 - 0.87)0.001003\,\frac{m^3}{\text{kg}} + (0.87)2.828\,\frac{m^3}{\text{kg}} = 2.46\,\frac{m^3}{\text{kg}}$$

$$V_{tank} = 15\text{ kg}\left(2.46\,\frac{m^3}{\text{kg}}\right) = 36.9\, m^3$$

Partial and Saturation Pressures

- $P_{partial}$ $f(P \,\&\, T)$ is the pressure exerted by a single component in a gaseous mixture if it existed alone in the same volume occupied by the mixture and at the same temperature and pressure of the mixture.
- P_{sat} $f(T)$ is the pressure at which liquid and vapor phases are at equilibrium at a given temperature.
- The Antoine equation may be used to estimate the saturation pressure:

$$\ln P_{sat} = A - \frac{B}{T + C}$$

P in kPa and T in $°C$

where A, B, and C are the Antoine constants

Table 1.13 Antoine constants[a] for some components: P is in kPa and T is in °C

Species	A	B	C	Range (°C)
Acetone	14.314	2756.22	228.06	−26 to −77
Acetic acid	15.071	3580.80	224.65	24 to −142
Benzene	13.782	2726.81	217.57	6 to −104
1-Butanol	15.314	3212.43	182.73	37 to −138
iso-Butanol	14.604	2740.95	166.67	30 to −128
Carbon tetrachloride	14.057	2914.23	232.15	−14 to −101
Chloroform	13.732	2548.74	218.55	−23 to −84
Ethanol	16.895	3795.17	230.92	3 to −96
Ethyl benzene	13.972	3259.93	212.30	33 to −163
Methanol	16.578	3638.27	239.50	−11 to −83
Methyl acetate	14.245	2662.78	219.69	−23 to −78
1-propanol	16.115	3483.67	205.81	20 to −116
2-propanol	16.679	3640.20	219.61	8 to −100
Toluene	13.932	3056.96	217.62	13 to −136
Water	16.387	3885.70	230.17	0 to −200

Energy Forms

Energy Forms

$$\Sigma E_{forms} = E_{total}$$

Energy exists in numerous forms such as

E: capacity to do **work** or to produce **heat**

Thermal

mechanical

Electric

Chemical

Nuclear

Mass

- In **closed systems** (fixed mass) E transfers as heat (under T difference) and by work (by a force acting through a distance).
- In **open systems** (control volumes), E transfers by mass flow as well as heat and work.

Energy transfer

Energy may transfer via:

Open System → Work + Heat + Mass

Closed System → Work + Heat

Isolated System → None

Energy conservation?

- The "energy conservation" reflects not only the quantity conservation but also, and more importantly, the quality conservation.

- Electricity, which is of the highest quality of energy can always be converted to an equal amount of thermal energy (heat).

- Only a small fraction of thermal energy, which is the lowest quality of energy, can be converted back to electricity.

Energy storage

Energy is stored in:

Potential E | **Kinetic E**

- A **system** is like a **bank**: it accepts deposits in either currency, but stores its reserves as **internal energy**, U

$$\sum PE + KE = U$$

Energy Storage in Fuels

- Hydrogen represents a store of potential energy (fusion of hydrogen in the Sun).

- Some of the fusion energy is transformed into sunlight, which may again be stored as gravitational potential energy after it strikes the earth.

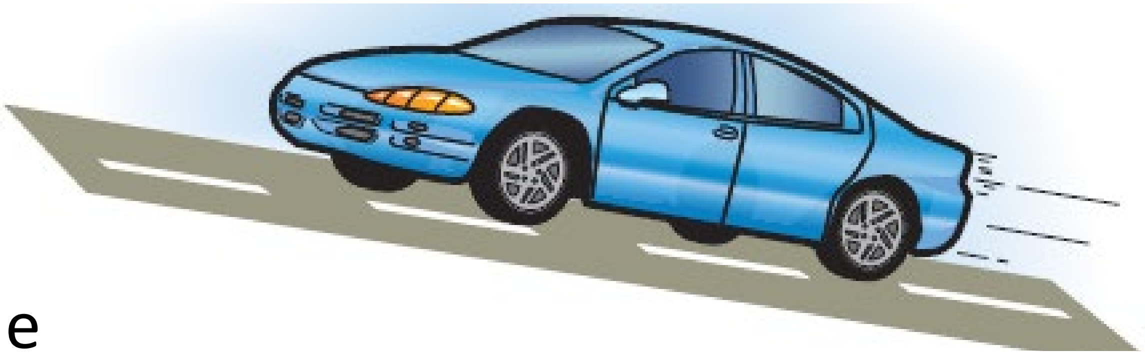
Macroscopic E forms

- are those a system possesses as a **whole** as consequence of its **motion** (is called **Kinetic Energy**, KE) or under the influence of some **external** effects as gravity (is called **Potential Energy**, PE), {magnetism, electricity, and surface tension}{are usually ignored}.

$$KE(kJ) = \frac{mV^2}{2}$$

V: velocity of the system relative to some fixed reference frame

$$ke(kJ/kg) = \frac{V^2}{2}$$



The macroscopic energy of an object changes with velocity and elevation

The kinetic energy of a rotating solid body $= \frac{I\omega^2}{2}$

where I is the moment of inertia of the body and ω is the angular velocity.

- The energy that a system possesses as a result of its elevation in a gravitational field is called **potential energy** (PE) and is expressed as:

$$PE(kJ) = mgz \qquad pe(kJ/kg) = gz$$

where g is the gravitational acceleration and z is the elevation of the center of gravity of a system relative to some arbitrarily selected reference level.

Microscopic E forms

- are related to molecular structure of a system and degree of molecular activity.
- They are **independent** of **outside** reference frames.
- They represent the sum of kinetic and potential energies of molecules composing the system.
- The sum of all microscopic forms of energy is called **internal energy** of a system and is denoted by U.

Internal KE of molecules

Translational Energy

Movement of the molecules with some velocity

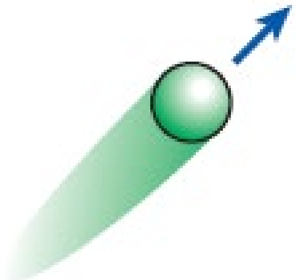
Rotational Energy

Rotations of atoms in polyatomic molecules about an axis

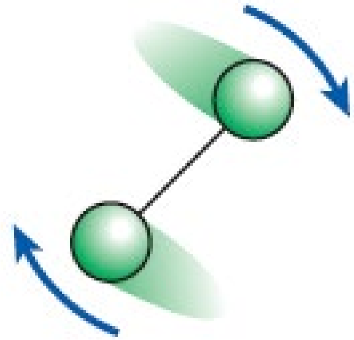
Vibrational Energy

Vibrating of atoms in polyatomic molecules about their common center of mass

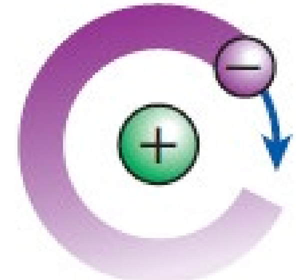
Microscopic motions



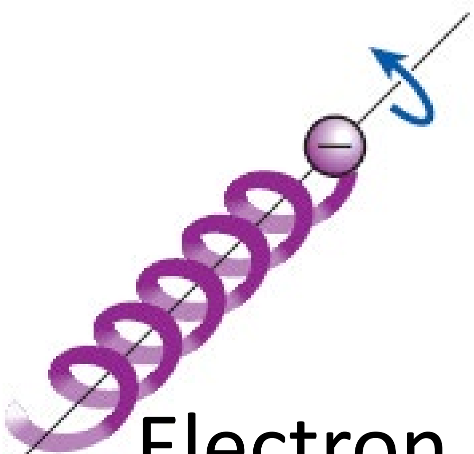
Molecular translation



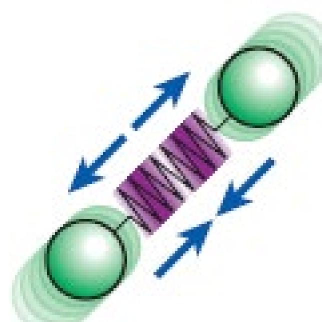
Molecular rotation



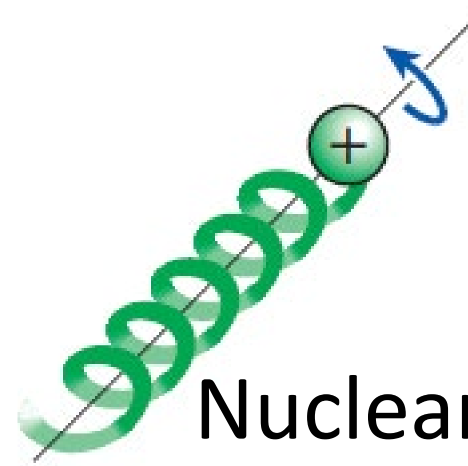
Electron translation



Electron spin



Molecular vibration



Nuclear spin

Sensible Energy

- Portion of internal energy of a system associated with KE of atoms and molecules (translational, rotational, and vibrational effects).

- Average velocity and degree of activity of gas molecules are proportional to T.

- As T ↑, KE ↑ and U↑ .

Internal Potential Energy

- The internal energy is also associated with various **binding forces** between the molecules of a **substance**, between the atoms within a **molecule**, and between the particles within an **atom** and its **nucleus**.

- The forces that bind the molecules to each other are strongest in solids (least reactive) and weakest in gases.

Latent Energy

- If sufficient energy is added to the molecules of a solid or liquid, the molecules overcome these molecular forces and break away, turning the substance into a gas (phase-change process).
  - Because of this added energy, a system in the gas phase is at a higher internal energy level than it is in the solid or the liquid phase.
  - The internal energy associated with the phase of a system is called the **latent energy**.
  - The phase-change process occur mostly **without** a change in the chemical composition of a system.

Thermal E = Sensible E + latent internal energy

Chemical and Nuclear Energy

- The internal energy associated with the atomic bonds (interaction of valence electrons) in a molecule is called **chemical energy**.
  - During a chemical reaction, such as a combustion process, some chemical bonds are destroyed while others are formed. As a result, the internal energy changes.
- The **nuclear forces** are much larger than the forces that bind the electrons to the nucleus. The tremendous amount of energy associated with the strong bonds within the nucleus of the atom itself is called **nuclear energy**.
  - A **nuclear reaction** involves changes in the core or nucleus. Therefore, atoms loses its identity.

Static/dynamic forms of Energy

- The forms of energy that constitute the total energy of a system and can be ***contained*** or ***stored*** in a system are viewed as the ***static*** forms of energy.

- The forms of energy not stored in a system can be viewed as the ***dynamic*** forms of energy or as *energy* ***interactions***. These are recognized at the system **boundary.**

Dynamic forms of Energy

- The only two forms of **energy interactions** associated with a **closed** system are **heat transfer** (if T is different) and **work**.

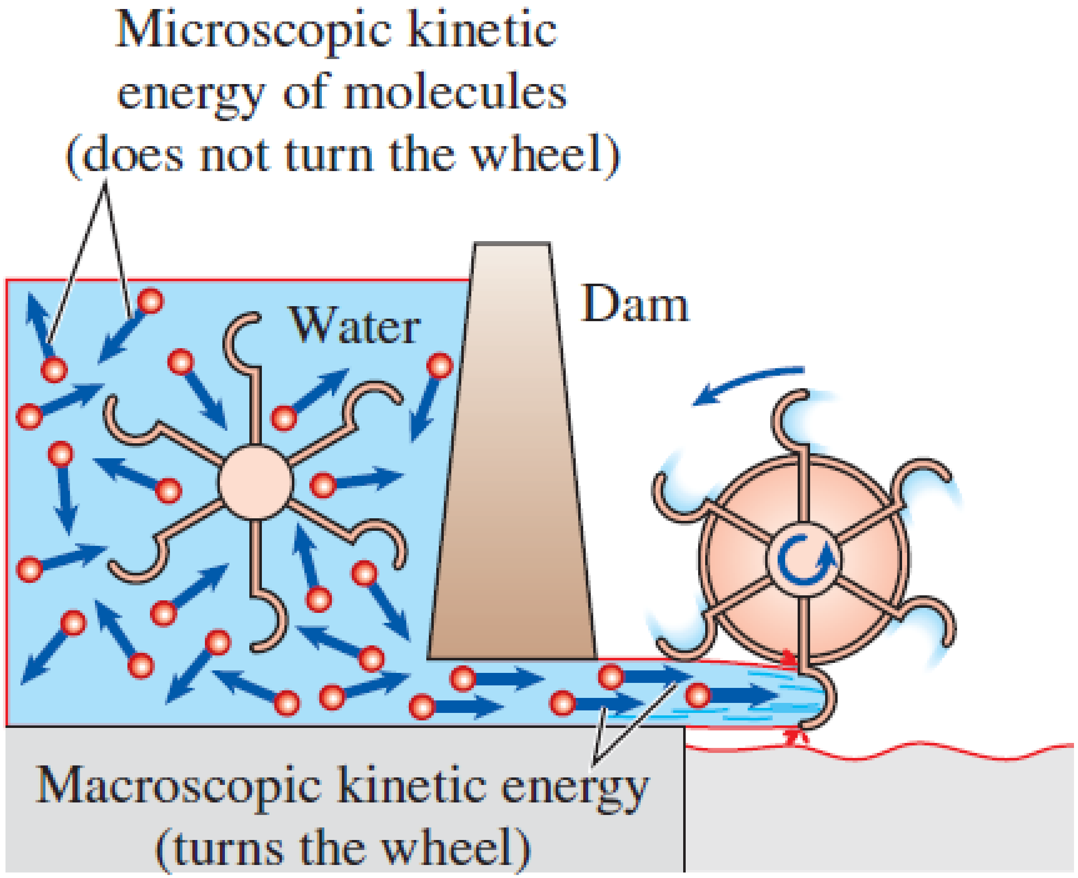
- A **control volume** can also exchange energy via **mass transfer**.

Macroscopic/Microscopic KE

- The macroscopic kinetic energy of an object is an ***organized*** form of energy associated with the **orderly** motion of all molecules in one direction in a straight path or around an axis.

- In contrast, the microscopic kinetic energies of the molecules are completely ***random*** and highly ***disorganized***.

- The organized energy is much more valuable than the disorganized energy, and a major application area of thermodynamics is the conversion of disorganized energy (**heat**) into organized energy (**work**).



Organized energy can be converted to **disorganized** energy completely, but only a fraction of **disorganized** energy can be converted to **organized** energy by **heat engines**.

Total Energy, E

- In absence of magnetic, electric, and surface tension effects, E of a system consists of KE (**macroscopic**), PE (**macroscopic**), and internal energies, U.

$$E = U + KE + PE$$

$$E = U + \frac{1}{2}mV^2 + mgz \quad (kJ)$$

on a unit mass basis,

$$e = u + \frac{1}{2}V^2 + gz \quad (kJ/kg)$$

Stationary Systems

- Most closed systems remain stationary (i.e., their macroscopic velocity and elevation of the center of gravity remain constant during a process).

- In absence of other external influences, **stationary systems** experience no change in their macroscopic KE and PE.

$$\Delta E = \Delta U$$

A closed system is assumed to be stationary unless stated otherwise.

Control Volume Systems

- involve fluid flow for long periods of time.
- is convenient to express the energy flow in the rate form.
- The **mass flow rate** $\dot{m}$ is the amount of mass flowing through a cross section per unit time.
- The **volume flow rate** $\dot{V}$ is the volume of a fluid flowing through a cross section per unit time.

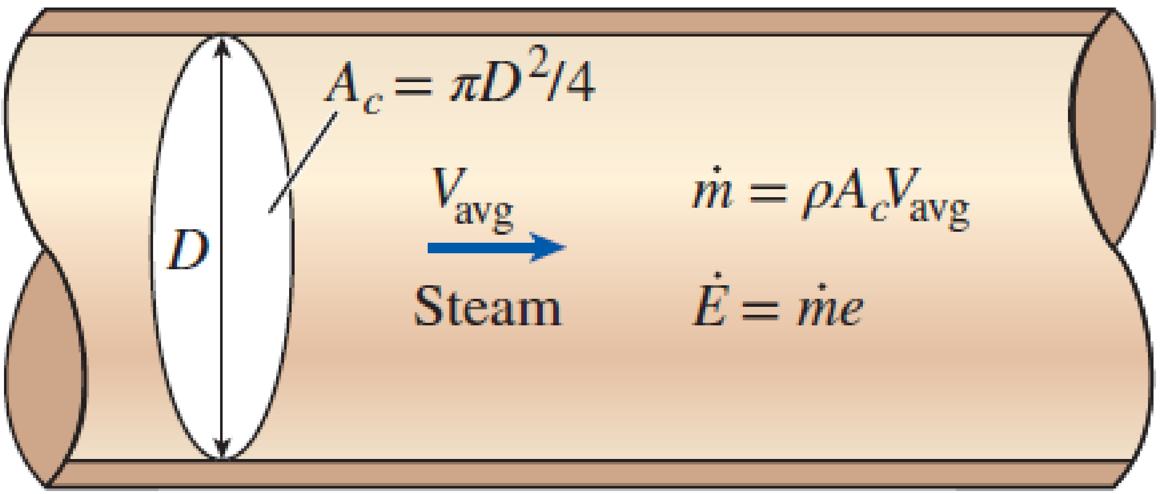
$$\dot{m} = \rho \dot{V} = \rho A_c V_{avg} \qquad \text{(kg/s)}$$

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. The dot over a symbol is used to indicate time rate.

- The energy flow rate associated with a fluid flowing at a rate of $\dot{m}$ is

$$\dot{E} = \dot{m}e \qquad (\text{kJ/s}) \; or \; \text{kW}$$

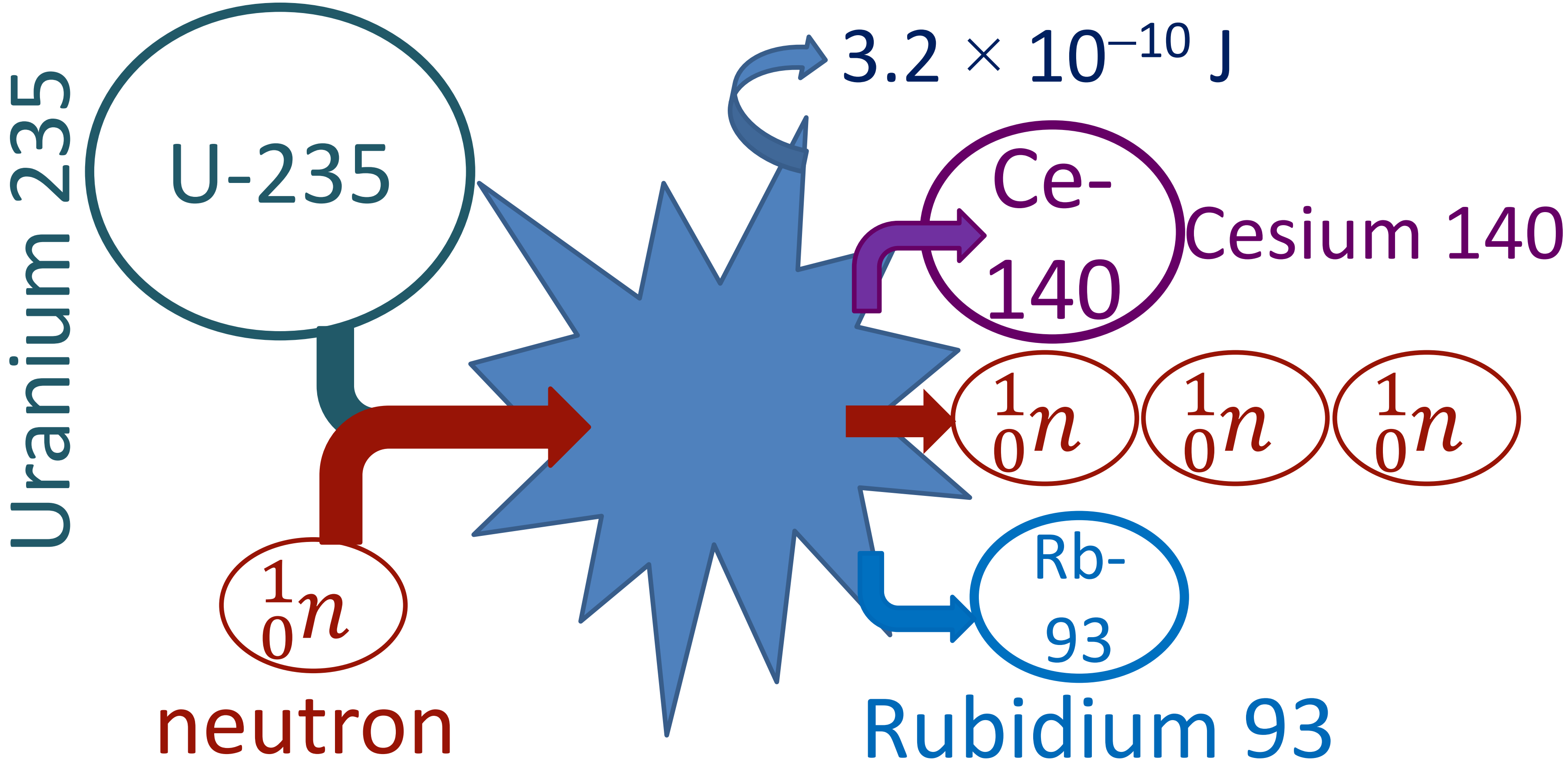
e : **energy per unit mass**



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}.

Nuclear fission (splitting of U-235 isotope)

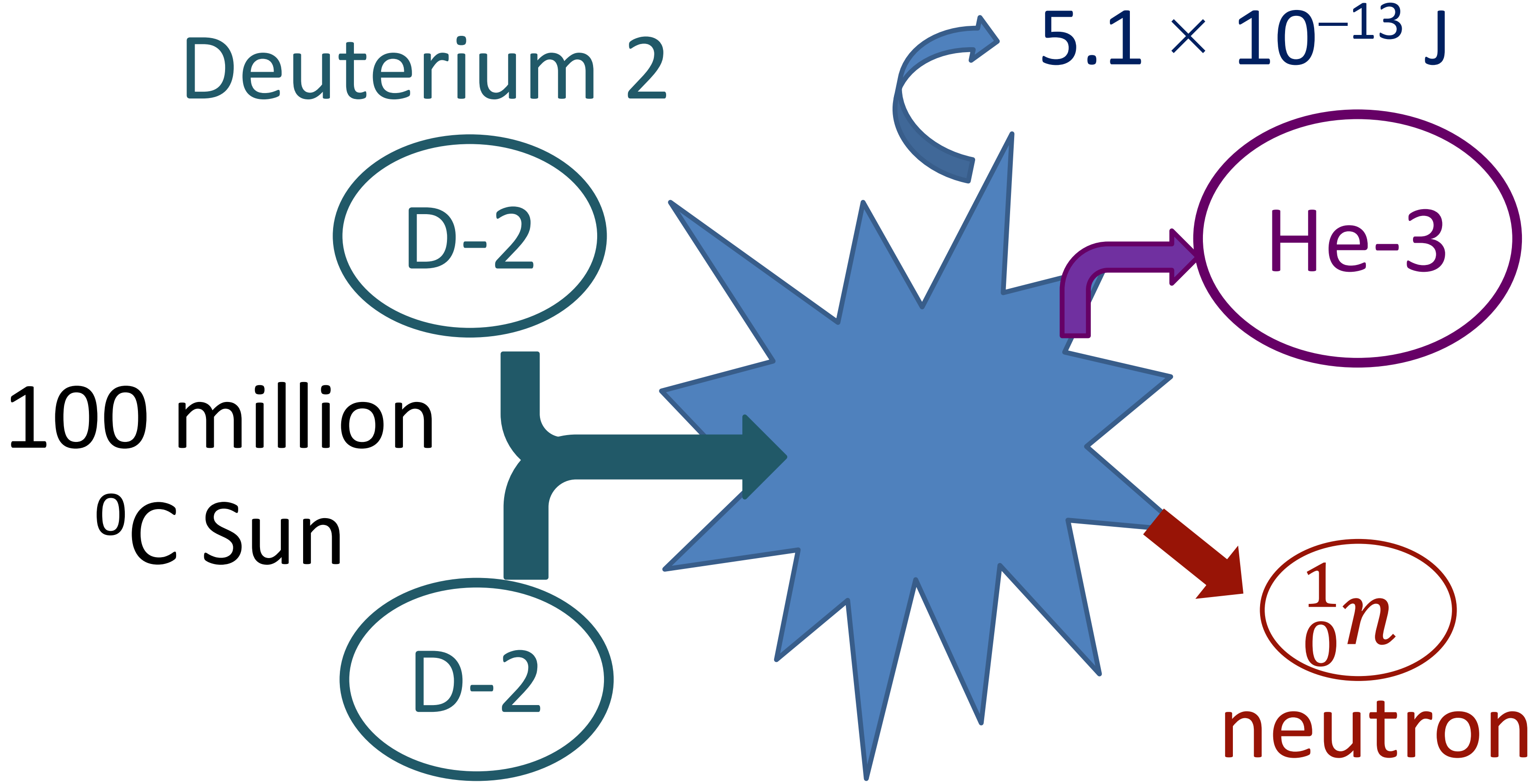
$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{55}Ce + ^{93}_{37}Rb + 3\,^{1}_{0}n + (3.2 \times 10^{-10} J)$$



1 kg of U-235 releases **8.314×10^{10} kJ of heat** >>> **Q** released when 3700 tons of coal are burned.

Nuclear fusion (H-2 isotope/Deuterium)

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{2}He + ^{1}_{0}n + (5.1 \times 10^{-13} J)$$



Difficult because of strong repulsion between the positively charged nuclei.

A gasoline-powered Car

- An average car consumes about 5 L of gasoline a day, and the capacity of the fuel tank of a car is about 50 L. Therefore, a car needs to be refueled once every 10 days. Also, the density of gasoline ranges from 0.68 to 0.78 kg/L, and its lower heating value is about 44,000 kJ/kg (that is, 44,000 kJ of heat is released when 1 kg of gasoline is completely burned). Suppose a car is equipped with 0.1 kg of U-235, determine if this car will ever need refueling? (1 kg of U-235 = 8.314×10^{10} kJ)

Answer

Nuclear Fuel

Mass of gasoline used per day

Solution

$$m_{gasoline} = (\rho V)_{gasoline} = \left(\frac{0.75\ kg}{L}\right)\left(\frac{5\ L}{day}\right)$$
$$= 3.75\ kg/day$$

E supplied to the car per day

$$E = (m_{gasoline})\,(Heating\ \ value)$$
$$= \left(\frac{3.75\ kg}{day}\right)\left(\frac{44{,}000\ kJ}{kg}\right) = \left(\frac{165{,}000\ kJ}{day}\right)$$

Complete fission of 0.1 kg of uranium-235 releases

$$(8.314 \times 10^{10}\ \text{kJ/kg})(0.1\ \text{kg}) = 8.314 \times 10^{9}\ \text{kJ}$$

$$No.\ \text{of days} = \frac{\text{Energy content of fuel}}{\text{Daily energy use}} = \frac{8.314 \times 10^{9}\ \text{kJ}}{165{,}000\ kJ/day}$$

$$= 50{,}390\ day = 138\ years$$

Mechanical Energy

- Energy form that can be converted to mechanical work completely and directly by an ideal mechanical device (turbine, pump).

- Concerns with the transportation of a fluid from one location to another at a specified flow rate, velocity, and elevation difference, and the system may generate mechanical work in a **turbine** or it may consume mechanical work in a **pump** or **fan** during this process.

Mechanical Energy

- A pump transfers mechanical energy to a fluid by raising its pressure, and a turbine extracts mechanical energy from a fluid by dropping its pressure.

- KE and PE are the familiar forms of mechanical energy.

- Thermal (although being a form of KE) energy is not mechanical energy, however, since it cannot be converted to work directly and completely.

A pump converts mechanical E (Torque on shaft) to Hydraulic E (Water Under Pressure)

Hand water pump

A turbine operates oppositely

Pump/Flow Energy

$$P(Pa) = \frac{N}{m^2} = \frac{N\,m}{m^3} = \frac{J}{m^3}$$

$$\frac{P}{\rho} = \frac{Pa}{kg\,m^{-3}} = \frac{J\,m^{-3}}{kg\,m^{-3}} = \frac{J}{kg}$$

- The pressure of a flowing fluid is associated with its mechanical energy.
- Pressure itself is not a form of energy, but the pressure force acting on a fluid through a distance producing work is called ***flow work***, in the amount of P/ρ per unit mass.
- **Flow work** is expressed in terms of fluid properties, and it is convenient to view it as part of the energy of a flowing fluid and call it ***flow energy***.

- The mechanical energy of a flowing fluid can be expressed on a unit mass basis as

$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

all per unit mass

Flow energy ($\frac{P}{\rho}$), KE ($\frac{V^2}{2}$), PE (gz)

$\dot{m}$:mass flow rate of a fluid

$$\dot{E}_{mech} = \dot{m} e_{mech} = \dot{m}\left(\frac{P}{\rho} + \frac{V^2}{2} + gz\right)$$

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

$$\Delta e_{mech} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \qquad \text{(kJ/kg)}$$

$$\Delta \dot{\boldsymbol{E}}_{mech} = \dot{m}\Delta e_{mech}$$

$$= \dot{m}\left(\frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right) \quad (\text{kW})$$

- The mechanical energy of a fluid does not change during flow if its pressure, density, velocity, and elevation remain **constant**.

- In the absence of any irreversible losses, the mechanical energy change represents the **mechanical work** supplied to the fluid (if $\Delta \boldsymbol{e}_{mech} > \mathbf{0}$, **pump**) or extracted from the fluid (if $\Delta \boldsymbol{e}_{mech} < \mathbf{0}$, **turbine**).

- The maximum (ideal) power generated by a **turbine**, for example, is

$$\dot{W}_{max} = \dot{m}\Delta e_{mech}$$

Example: Wind Energy

- A site evaluated for a wind farm is observed to have steady winds at a speed of 8.5 m/s. Determine the wind energy (*a*) per unit mass, (*b*) for a mass of 10 kg, and (*c*) for a flow rate of 1154 kg/s for air.

Answer

Assumption: wind flows steadily at the specified speed.

Analysis: The only harvestable form of energy of atmospheric air is the kinetic energy, which is captured by a wind turbine.

(a) Wind energy per unit mass of air is

$$e_{mech} = ke = \frac{V^2}{2} = \frac{(8.5\ m/s)^2}{2}\left(\frac{1\ J/kg}{1\ m^2/s^2}\right) = 36.1\ J/kg$$

(b) Wind energy for an air mass of 10 kg is

$$\boldsymbol{E_{mech}} = m e_{mech} = m\left(\frac{V^2}{2}\right)$$

$$= 10\ kg \times (36.1\ J/kg) = 361\ J$$

(c) Wind energy for a mass flow rate of 1154 kg/s is

$$\dot{\boldsymbol{E}}_{\boldsymbol{mech}} = \dot{m} e_{mech} = \dot{m}\left(\frac{V^2}{2}\right)$$

$$= (1154\ kg/s) \times (36.1\ J/kg) \times \frac{1\ kW}{1000\ J/s} = 41.7\ kW$$

- This specified mass flow rate (1154 kg/s) corresponds to a 12-m-diameter flow section when the air density is 1.2 kg/m^3.

- Therefore, a wind turbine with a span diameter of 12 m has a power generation potential of 41.7 kW.

- Real wind turbines convert about one-third of this potential to electric power.

CYU

- Select the correct list of energy forms that constitute internal energy:

  (A) Sensible, chemical, and kinetic

  (B) Sensible, latent, chemical, and nuclear

  (C) Sensible, chemical, and nuclear

  (D) Sensible and latent

  (E) Potential and kinetic

Answer

√ **(B) Sensible, latent, chemical, and nuclear**

CYU

- To what velocity (m/s) do we need to accelerate a car at rest to increase its kinetic energy by 1 kJ/kg?

(A) 1 (B) 1.4 (C) 10 (D) 44.7 (E) 90

Answer

√ **(D) 44.7**

$$e_{mech} = ke = \frac{V^2}{2} = 1000\ J/kg$$

$$V = 44.7\ \text{m/s}$$

British thermal unit (Btu)

- is the energy unit in the English system needed to raise the temperature of 1 lb_m of water at 68°F by 1F.

ton of oil equivalent (TOE):
1 TOE = 11630 kWh = 41870 MJ.

Name of unit	Symbol	Definitions
British thermal unit	Btu	1055 J = 5.4039 psia ft^3
Btu/lb_m	Btu/lb_m	2.326 kJ/kg
Joule	J	$J = m \cdot N = 1\ kg \cdot m^2/s^2$
Calorie	Cal	4.1868 J
kJ	kJ	kPa m^3 = 1000 J
kJ/kg	kJ/kg	0.43 Btu/lb_m
Erg	erg	$g \cdot cm^2/s^2 = 10^{-7}$ J
Foot pound force	ft lb_f	$g \times lb \times ft = 1.355$ J
Horsepower hour	hph	$hp \times h = 2.684 \times 10^6$ J
Kilowatt hour	kWh	$kW \times h = 3.6 \times 10^6$ J
Quad	quad	10^{15} Btu = 1.055×10^{18} J
Atmosphere liter	atml	$atm \times l = 101.325$ J
kW	kW	3412 Btu/h
Horsepower	hp	2545 Btu/h
Therm	therm	29.3 kWh
Electronvolt	eV	$\approx 1.602\ 17 \times 10^{-19} \pm 4.9 \times 10^{-26}$ J