

13: Heat and Thermodynamics

Key Physics Terms

- **Thermodynamics:** The study of processes in which energy is transferred as work or heat.
- **Temperature:** A measure of the average kinetic energy of the particles. The higher the temperature the faster the molecules move.
- **Linear Expansion:** A change in length of a solid due to a temperature change. Proportional to the linear expansion coefficient, α , for the material.
- **Volume Expansion:** A change in volume of a solid due to a temperature change. Proportional to the volume expansion coefficient, β , for the material. Note $\beta = 3\alpha$.
- **Energy:** The ability to do work or supply heat.
- **System:** The object or objects being studied.
- **Surroundings:** Everything surrounding the system.
- **Internal Energy:** The total energy of all the molecules in the system.
- **Heat:** The transfer of energy from one object to another due to a difference in temperature.
- **Work:** In thermodynamics the work done **by** the system is positive; the work done **on** the system is negative.
- **Calorie:** The amount of heat required to raise the temperature of 1g of water by 1°C. 1 calorie = 4.18 Joules.
- **State Functions:** Quantity which is dependent only on the current state of the system not the path taken to reach that state, e.g. Temperature.
- **Specific Heat Capacity:** The amount of energy required to change a unit mass of a substance by 1°C.
- **Heat Capacity:** The amount of heat needed to raise a mass of a substance, given by the product of mass and specific heat capacity.
- **Endothermic reactions:** A reaction in which energy is absorbed into the system from the surroundings.
- **Exothermic reactions:** A reaction in which energy is released from the system into the surroundings.
- **Calorimetry:** A quantitative measurement of energy lost/gained from the system, which is equal & opposite to that lost/gained from the surroundings.
- **Latent Heat:** The energy required to change the phase of a substance, without changing the temperature of the substance.
- **Heat of fusion:** The heat required to change 1kg of a substance from a solid to a liquid state, which is equal to the heat lost when the liquid changes to a solid state.
- **Heat of vaporization:** The heat required to change 1kg of a substance from a liquid to a vapor phase, which is equal to the heat lost when the vapor changes to a liquid phase.
- **Thermal Equilibrium:** Two objects in thermal contact cease to exchange net energy.
- **Zeroth Law of Thermodynamics:** If two systems are separately in thermal equilibrium with a third system. The first two systems are in thermal equilibrium with each other.
- **1st Law of Thermodynamics (Law of Conservation of Energy):** When heat flows into a system the energy must either appear as increased internal energy or work done by the system on its surroundings.
- **Entropy:** A quantitative measure of the disorder of a system.
- **2nd Law of Thermodynamics:** The total entropy of the universe can never decrease. Natural processes tend towards disorder, greater entropy.
- **Heat Engine:** A device that converts thermal energy into mechanical work.
- **Ideal Heat Engine:** An engine with an efficiency of 1.
- **Efficiency:** The ratio of the work done by the heat engine to the heat input to the engine.

Variables Used and Their Metric Units

- **T = Temperature,** °C, K
- **α = Linear expansion coefficient,** (°C)⁻¹
- **β = Volume expansion coefficient,** (°C)⁻¹
- **L = Length,** m
- **V = Volume,** m³
- **U = Internal energy,** J
- **Q = Heat,** J
- **W = Work,** J
- **C_p = Specific heat ,** J/kg•°C
- **m = Mass,** kg
- **C = Heat capacity,** J/°C
- **L_{fus} = Heat of Fusion,** kJ/kg
- **L_{vap} = Heat of Vaporization,** kJ/kg
- **S = Entropy,** J/kg
- **ϵ = Efficiency**

Key Formulas

- $\Delta L = L \alpha \Delta T$
- $\Delta V = V \beta \Delta T$
- $\beta = 3\alpha$
- $Q = C_p m \Delta T$ or $Q = C \Delta T$ where $C = C_p m$
- $\Delta Q_{fus} = m \times L_{fus}$
- $\Delta Q_{vap} = m \times L_{vap}$
- $U = Q - W$
- $\Delta S_{univ} > 0$
- $\Delta S_{sys} + \Delta S_{sur} > 0$
- $\epsilon = \frac{W_{out}}{Q_{in}}$

1st Law of Thermodynamics

1st Law of Thermodynamics

When heat flows into a system the energy must either appear as increased internal energy or work done by the system on its surroundings. This is a statement of the conservation of energy.

$$U = Q - W$$

Q is the heat added to the system.

W is **positive** when work is done **by** the system on its surroundings: $U = Q - W$

W is **negative** when work is done **on** the system, by surroundings: $U = Q - (-W) = Q + W$

Special cases of the 1st Law

Adiabatic: No heat transfer, $Q = 0$, $\Delta U = -W = -P\Delta V$

Constant volume: No work is done, $W = 0$, $\Delta U = Q$

Cyclic: No change in internal energy, $\Delta U = 0$, $Q = -W$

Free expansion processes: Irreversible, $\Delta U = Q = W$

2nd Law of Thermodynamics

Entropy is a measure of disorder. If the entropy of the system decreases during a reaction, the entropy of the surroundings increases by an equal or greater amount.

Statements of the 2nd Law of Thermodynamics:

1) The total entropy of the universe can never decrease, only increase or remain the same. $\Delta S \geq 0$.

2) Heat flows from a hot object to a cold object but never the reverse.

3) There cannot be a 100% efficient heat engine; one that changes a given amount of heat entirely into work:

$$\epsilon = \frac{W_{out}}{Q_{in}} < 1$$

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