

Chapter Title: Waves - I

Sections: Standing Waves

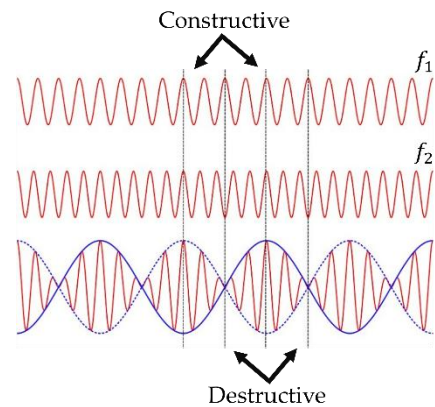
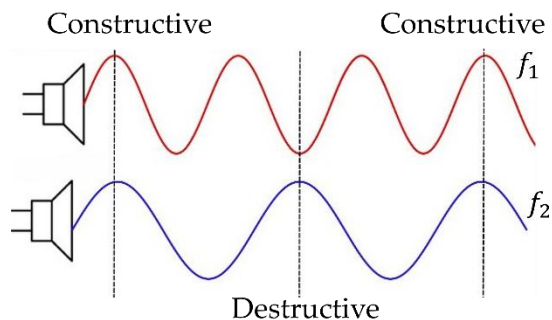
Chapter Title: Temperature, Heat, and the First Law of Thermodynamics

Sections: The Zeroth Law of Thermodynamics, Measuring Temperature, Thermal Expansion, Absorption of Heat, The Absorption of Heat by Solids and Liquids, 1st Law of Thermodynamics

Chapter Title: Entropy and the Second Law of Thermodynamics

Sections: The Second Law of Thermodynamics, Entropy

Beats



The interference of two sound waves with slightly different frequencies produces the interesting phenomenon known as beats.

Let us consider two wave functions $y_1(t)$ and $y_2(t)$. Here, $y_1(t) = A \sin(\omega_1 t)$ and $y_2(t) = A \sin(\omega_2 t)$.

Using the superposition principle, the beat wave equation is, $y(t) = y_1(t) + y_2(t)$

$$y(t) = 2A \cos \left[2\pi \left(\frac{\Delta f}{2} \right) t \right] \sin(2\pi f_{avg} t)$$

Here, $\Delta f = f_1 - f_2$ and $f_{avg} = (f_1 + f_2)/2$

Standing Waves

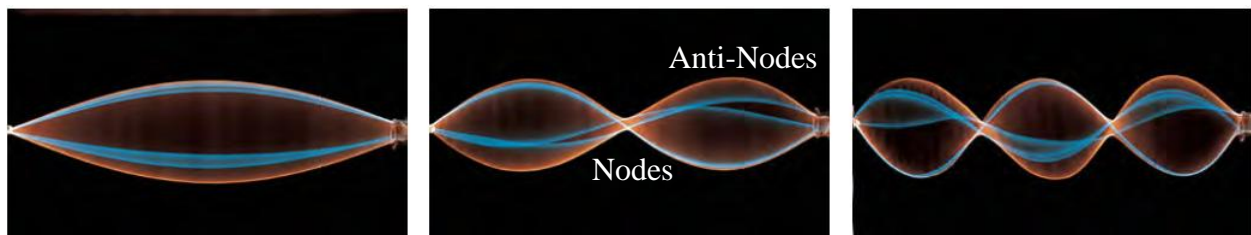


Figure: Here, N = Nodes: points at which the string never moves, A = Antinodes: points at which the amplitude of string motion is greatest

Standing waves are produced by the superposition of two traveling waves of the same frequency traveling in opposite directions.

Let us consider two wave functions y_1 and y_2 . Here, $y_1 = A \sin(kx - \omega t)$ and $y_2 = A \sin(kx + \omega t)$. According to the principle of superposition, $y = y_1 + y_2$

After solving the equations, $y = (2A \sin kx) \cos \omega t$

Here, the expression does not contain a function $(kx - \omega t)$, so it is not a single traveling wave. From this equation, nodes and antinodes are determined.

$$kx = 0, \pi, 2\pi, 3\pi, \dots$$

$$x = 0, \frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}, \dots$$

These are the positions of nodes.

$$kx = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \dots$$

$$x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \dots$$

These are the positions of antinodes.

Chapter Title: Temperature, Heat, and the First Law of Thermodynamics

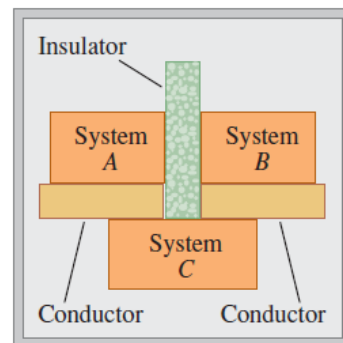
The Zeroth Law of Thermodynamics

If **C** is initially in thermal equilibrium with both **A** and **B**, then **A** and **B** are also in thermal equilibrium with each other.

This result is called the zeroth law of thermodynamics.

Two systems are in thermal equilibrium if and only if they have the same temperature.

Measuring Temperature



If C represents a Celsius temperature and T a Kelvin temperature, then

$$C = T - 273.15^\circ$$

$$\Rightarrow T = C + 273.15^\circ$$

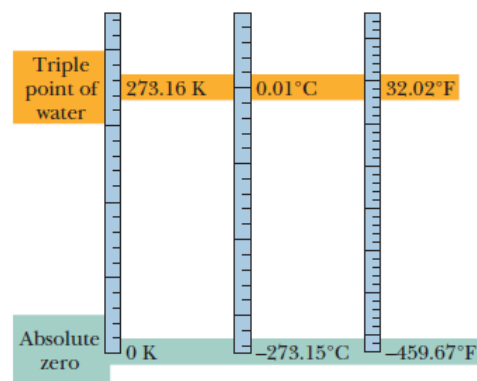
The relation between the Celsius and Fahrenheit scales is,

$$F = \frac{9}{5}C + 32^\circ$$

F is Fahrenheit temperature.

The Kelvin scale is called an absolute temperature scale,

and its zero point, $T = 0\text{ K} = -273.15^\circ\text{C}$



Thermal Expansion

Most materials expand when their temperatures increase.

Linear Expansion: If the temperature of a metal rod of length L is raised by an amount ΔT , its length is found to increase by an amount,

$$\Delta L = L\alpha\Delta T$$

Here, α is called a coefficient of linear expansion.

Volume Expansion: If the temperature of a solid or liquid whose volume is V is increased by an amount ΔT , the increase in volume is found to be,

$$\Delta V = V\beta\Delta T$$

Here, β is the coefficient of volume expansion of the solid or liquid. $\beta = 3\alpha$

Absorption of Heat

A change in temperature is due to a change in the thermal energy of the system because of a transfer of energy between the system and the system's environment.

Thermal energy is an internal energy that consists of the kinetic and potential energies associated with the random motions of the atoms, molecules, and other microscopic bodies within an object.

The transferred energy is called heat and is symbolized Q .

Heat is the energy transferred between a system and its environment because of a temperature difference that exists between them.

Heat is positive when energy is transferred to a system's thermal energy from its environment. We say that heat is absorbed by the system.

Heat is negative when energy is transferred from a system's thermal energy to its environment. We say that heat is released or lost by the system.

Unit: calorie (cal). The SI unit is joule (J).

$$1 \text{ cal} = 4.1868 \text{ J}$$

The Absorption of Heat by Solids and Liquids:

Heat Capacity: The heat capacity C of an object is the proportionality constant between the heat Q that the object absorbs or loses and the resulting temperature change ΔT of the object,

$$Q = C\Delta T = C(T_f - T_i)$$

Here, C is heat capacity, Unit: Joule per kelvin.

First Law of Thermodynamics

The internal energy E_{int} of a system tends to increase if energy is added as heat Q and tends to decrease if energy is lost as work W done by the system.

$$dE_{int} = dQ - dW$$

In some literature, $E_{int} = U$,

$$dQ = dU + dW$$

When heat dQ is added to a system, some of this added energy remains within the system, changing its internal energy by an amount dU ; the remainder leaves the system again as the system does work dW against its surroundings.

Work W is of two types:

1. Work done on a system
2. Work done by a system

We used work done on a system in previous chapters/ sections/ lectures.

$$-dW = -PdV = -P(V_f - V_i) = P(V_i - V_f)$$

Now, here we will be using work done by a system.

$$dW = PdV = P(V_f - V_i)$$

The work done on a system is always the negative of the work done by the system.

The first law of thermodynamics becomes,

When the work is done by a system,

$$dE_{int} = dQ - dW = dQ - PdV$$

That tells us, the internal energy tends to decrease if heat is lost by the system or if negative work is done on the system.

When the work is done on a system,

$$dE_{int} = dQ + dW = dQ + PdV$$

Which tells us, the internal energy of a system tends to increase if heat is absorbed by the system or if positive work is done on the system.

Thermodynamic Processes

From the first law of thermodynamics,

$$dE_{int} = dQ - dW$$

If $dQ = 0$, then $dE_{int} = -dW$

This process is called an adiabatic process.

An adiabatic process is one that occurs so rapidly or occurs in a system that is so well insulated that no transfer of energy as heat occurs between the system and its environment.

From the first law of thermodynamics,

$$dE_{int} = dQ - dW = dQ - PdV$$

If $dV = 0$, then $dE_{int} = dQ$

This process is called a constant-volume process or isochoric process.

Thus, if heat is absorbed by a system (that is, if dQ is positive), the internal energy of the system increases. Conversely, if heat is lost during the process (that is, if dQ is negative), the internal energy of the system must decrease.

From the first law of thermodynamics,

$$dE_{int} = dQ - dW$$

If $dQ = dW = 0$, then $dE_{int} = 0$

This process is called free expansion.

These are adiabatic processes in which no transfer of heat occurs between the system and its environment, and no work is done on or by the system.

Isothermal Process:

An isothermal process is a constant-temperature process.

For a process to be isothermal, any heat flow into or out of the system must occur slowly enough that thermal equilibrium is maintained.

In general, none of the quantities, E_{int} , Q , or W is zero in an isothermal process.

Isobaric Process:

An isobaric process is a constant-pressure process.

none of the quantities, E_{int} , Q , or W is zero in an isobaric process.

$$dW = P(V_i - V_f)$$

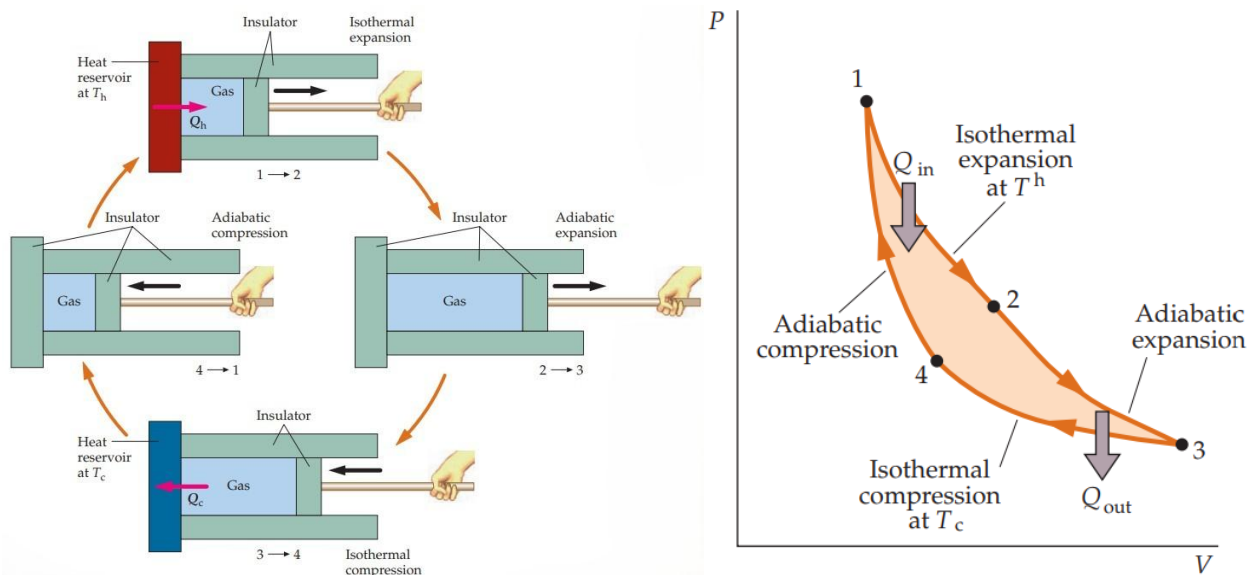
Thermodynamic Laws

The zeroth law of thermodynamics involves the concept of temperature

The first law involves the concept of internal energy

The second law of thermodynamics related to entropy

Temperature, internal energy, and entropy are state variables; that is, the value of each depends only on the thermodynamic state of a system, not on the process that brought it to that state.



Step 1: Heat is absorbed from a hot reservoir at temperature T_h during an isothermal expansion from state 1 to state 2.

Step 2: The gas expands adiabatically from state 2 to state 3, reducing its temperature to T_c .

Step 3: The gas releases heat to the cold reservoir as it is compressed isothermally at T_c from state 3 to state 4.

Step 4: The gas is compressed adiabatically until its temperature is again T_h .

In a reversible process, the system undergoing the process can be returned to its initial conditions along the same path on a PV diagram, and every point along this path is an equilibrium state.

A process that does not satisfy these requirements is irreversible.

Entropy

Entropy is nicely interpreted in the light of statistical mechanics.

In statistical mechanics, the behavior of a substance is described in terms of the statistical behavior of its atoms and molecules. An isolated systems tend toward disorder. Entropy is a measure of this disorder of a system.

Entropy, like pressure, volume, temperature, and internal energy, is a function of the state of a system.

It is presented by S .

$$dS = \frac{dQ_{rev}}{T} = \frac{dQ}{T}$$

The subscript rev on the quantity dQ_{rev} or simply dQ is a reminder that the transferred energy is to be measured along a reversible path even though the system may actually have followed some irreversible path.

When energy is absorbed by the system, dQ is positive and the entropy of the system increases.

When energy is expelled by the system, dQ is negative and the entropy of the system decreases.

Change in entropy, ΔS is defined as,

$$\Delta S = S_f - S_i = \int_i^f \frac{dQ}{T}$$

Here dQ is the energy transferred as heat to or from the system during the process, and T is the temperature of the system in kelvins.

An ‘entropy change, ΔS ’ depends on the energy transferred as heat and the temperature at which the transfer takes place.

Since T is always positive, the sign of ΔS is the same as that of dQ .

The SI unit for entropy and entropy change is the joule per kelvin.

Second Law of Thermodynamics

Kelvin–Planck form of the second law of thermodynamics states the following,

“It is impossible to construct a heat engine that, operating in a cycle, produces no effect other than the input of energy by heat from a reservoir and the performance of an equal amount of work”.

Kelvin’s statement,

“No system can absorb heat from a single reservoir and convert it entirely into work without additional net changes in the system or its surroundings”.