Thermal Energy: total kinetic energy of microscopic motion

\[ \text{ex. gas} = N \cdot \frac{1}{2} mv^2, \quad N = \text{# molecules} \]

other forms of internal energy, e.g., "springs" in molecules

Temperature: characterizes average energy of a molecule

\[ \frac{273}{293} \quad \frac{900}{930} \quad \frac{373}{\text{K (Kelvin)}} \]

scales:

\[ 0 \quad 20 \quad 100 \quad 180 \quad 32 \quad 68 \quad 212 \]

\[ \text{water freezes temp. water boils} \]

temperature between freezing and boiling

Thermal Energy is a bulk quantity \( \Rightarrow \) more stuff = more thermal energy

Temperature is a specific descriptive measure \( \Rightarrow \) higher temperature \( \Rightarrow \) more energy per molecule; \( E \sim kT \), \( k_B = 1.4 \times 10^{-23} \text{J/K} \) constant

Heat is flow of thermal energy (usually \( Q \))

2nd Law of Thermodynamics: Heat flows from hot to cold

one-way trip! total "Entropy" increases, \( Q \) can never decrease again (2nd Law)
Many examples of Entropy and 2nd Law

- Flow of heat from hot to cold
- Mixing: red paint + blue paint → purple
- Expansion: gas flowing into empty region
- Burning: mix $O_2$ and $H_2$ → $H_2O$ (oxidation)

Heat Engine uses some of thermal energy flowing from hot to cold → work

\[ Q_h \text{ extracted from hot object} \]
\[ W \text{ converted into work} \]
\[ Q_c \text{ flows into cold object} \]

\[ \text{Work: } Q_h = W + Q_c \text{ (Law)} \]

\[ \text{efficiency: } \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h} \]

Some heat has to flow into cold

\[ Q_c > 0 \implies \text{ efficiency } < 100\% \]

Max. theoretical efficiency = $1 - \frac{T_c}{T_h}$ (Kelvin!!)

ex. gas engine $T_h = 700^\circ C = 1000 \text{ K}$
\[ T_c = 340^\circ C = 600 \text{ K} \]

max efficiency $= 1 - \frac{600}{1000} = 0.4 = 40\%$