Temperature and Heat.

What is temperature, T.? (in our perspective)

T quantifies physical properties of matter consists of numerous particles / molecules.

T $\longleftrightarrow$ state characterised by macroscopic quantities: Pressure, Volume, resistance ...

e.g. thermometer:

T $\longleftrightarrow$ Volume of liquid. T↑ V↑.

Resistor in circuit

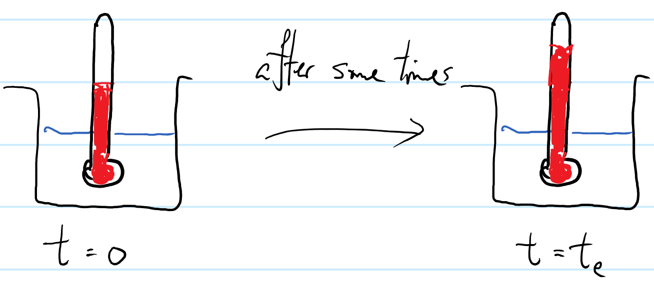
T $\longleftrightarrow$ resistance. T↑ R↑

Thermal Equilibrium.

Thermal contact — energy transfer is allowed between two systems

When the states of two thermally contacting systems remain unchanged, the systems are called, being in thermal equilibrium.

e.g. a thermometer in water



no more changes.

⇒ Thermometer & water are in thermal equilibrium.

⇓

we also say that

They have the same Temperature!

Thermal Equilibrium = same temperature.

Zero-th Law of Thermodynamics

If A & B are each in thermal eqilibrium with C,

then A & B are in thermal equilibrium with each other.

Different units/scales of temperature.

Fahrenheit (T_F)	Celsius (T_c)	Kelvin (T)
• Freezing point of water $32°F$	• Freezing point of water $0°C$	◦ Lowest possible temp. $0\ K$
• Boiling point of water $212°F$	• Boiling point of water $100°C$	◦ Triple pt. of water $273.16\ K$ ($= 0.01°C$) @ $p = 0.006$ atm.
• human body temp. $\sim 96°F$	• human body temp. $\sim 37.5°C$	
set to fit human body temp.	set to fit water freezing & boiling pt.	most objective scale (more in Lecture 23-24)

Conversion:

$$T_F = \frac{9}{5} T_c + 32$$

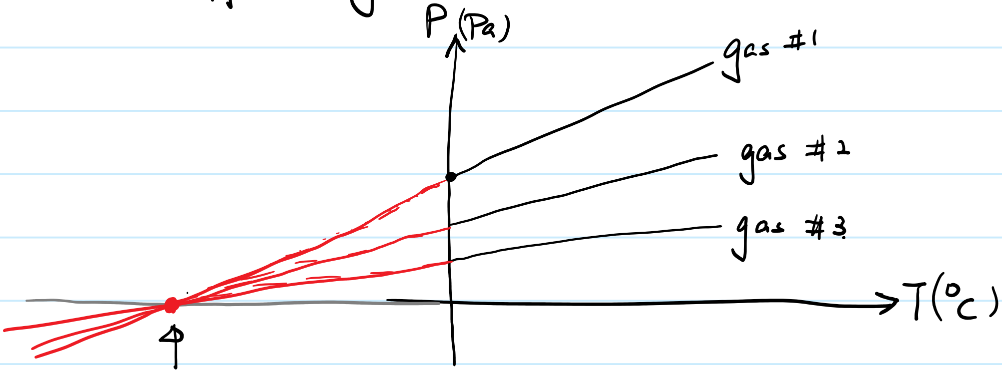
$$T_c = T - 273.15\,K$$

Temperature and gas

Given a container filled with gas at a fixed volume,

Temp. $\propto$ Pressure of the gas.

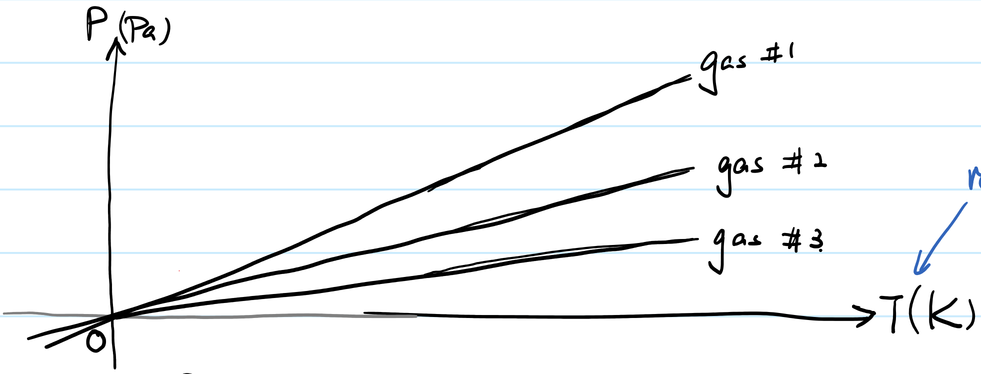
For different gases,



T_0 @ $P = 0$.

absolute zero. $T_0 = -273.15\,°C = 0\ K$.

Plotting the diagram with the new T-axis in unit of Kelvin:



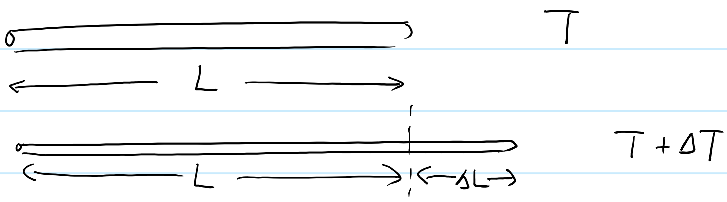
$$\frac{P}{T} = \text{constant}$$ (value can be different for different gas)

Kelvin Scale can be determined using water at fixed volume and its triple point as,

$$T = \frac{P}{P_3} T_3 = \frac{273.16}{0.006} \frac{K}{atm} \cdot P$$

Thermal Expansion

Linear expansion



$$\text{fractional change} = \frac{\Delta L}{L} \propto \Delta T$$

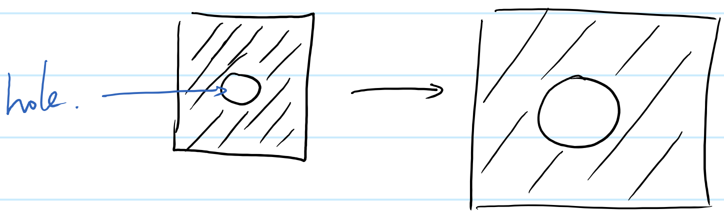
$$\Rightarrow \quad \frac{\Delta L}{L} = \alpha\, \Delta T \xrightarrow{\text{infinitesimal change}} \frac{dL}{L} = \alpha\, dT$$

coefficient of linear expansion.

e.g. $\alpha_{\text{Aluminimum}} = 2.4 \times 10^{-5} \ K^{-1}$

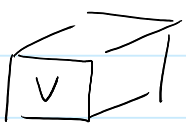
$\alpha_{\text{glass}} = 0.4 \times 10^{-5} \ K^{-1}$

open cold jar lid $\Rightarrow$ warm the lid.
lid expands more than glass.



hole expands too

Volume expansion.



$$\frac{\Delta V}{V} = \beta\, \Delta T \longrightarrow \frac{dV}{V} = \beta\, dT$$

e.g. $V = L^3$ (cube) $\Rightarrow \quad \frac{dV}{V} = \frac{1}{L^3}\, 3L^2\, dL = 3\frac{dL}{L} = 3\alpha\, dT$

$$\equiv \beta\, dT$$

$\underline{\beta = 3\alpha}$.

<u>Heat</u> = energy transfer due to temperature difference. (instead of work)

Heat and temperature change

Heat $\Delta Q > 0$ if Heat enters to the system

$\Delta Q < 0$ if Heat exits from the system

for any object

$$\Delta Q = C_{bulk} \Delta T$$

C_{bulk} = heat capacity of the object, which can be a mixture of different materials (bulk)

for single material

$$\Delta Q = m c \Delta T ,$$

c = specific heat of the material

e.g. water $c_w \sim 4200\ J/kg/K$

for gas

$$\Delta Q = n C_{mol} \Delta T ,$$

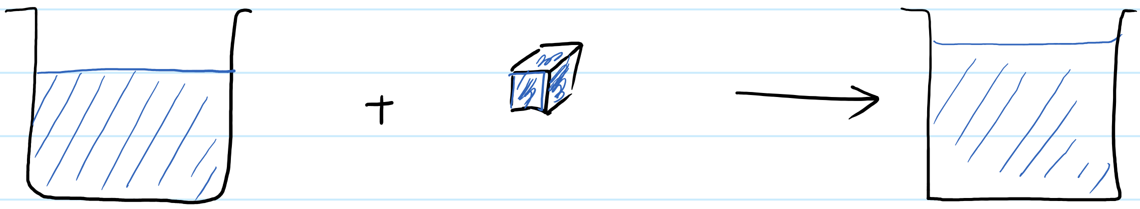
C_{mol} = molar heat capacity

<u>Latent Heat</u> - Amount of heat per one unit of mass to change the sustance from <u>one phase</u> to another.

e.g. gas, liquid, solid...

- During the phase change/transition, $\Delta T = 0$
  e.g. vapourization, freezing ...

Example.



Water: $m_w = 0.25\,kg$, $T_w = 25°c$

Ice: $m_I = ?$, $T_I = -20°c$

Water: $T_f = 0°c$

Find m_I.

Assumming the process occurs in a thermal insulator.

$$\Delta Q_{sys} = 0$$

$$\Delta Q_{water} + \Delta Q_{ICE} = 0$$

$$\Delta Q_{water} = m_w c_w \Delta T = m_w c_w (T_f - T_w)$$

$$\Delta Q_{ICE} = \Delta Q_{melting} + \Delta Q_{T_I \to T_f}$$

$$= + m_I L_{fusion} + m_I c_I (T_f - T_i)$$

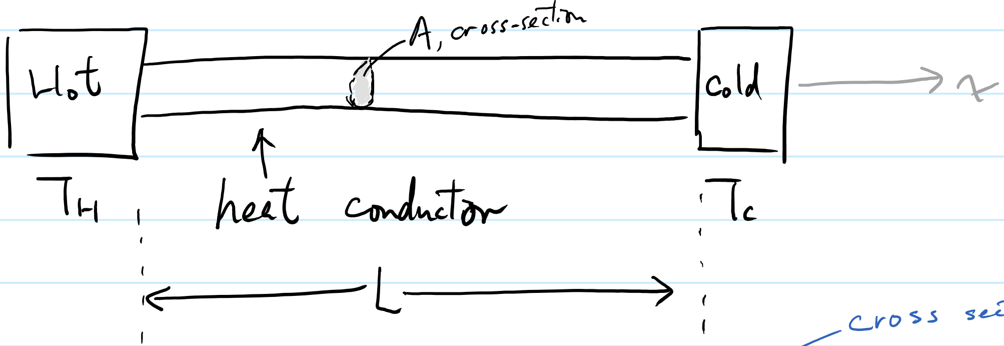
Ice absorbs energy in melting

$$\Rightarrow \quad m_I = \frac{m_w c_w (T_f - T_w)}{c_I (T_f - T_I) + L_{fusion}}$$

Mechanism of Heat Transfer

Conduction, Convection & Radiation

Conduction (physical contact)



cross section area

$$\text{Heat flow per unit time} = H = k\,A\,\frac{(T_H - T_c)}{L}$$

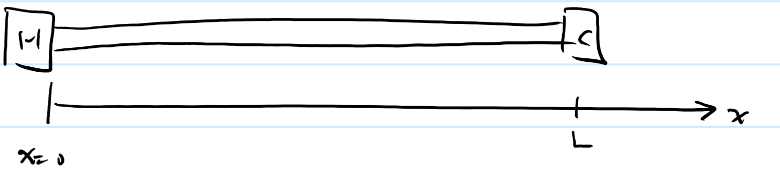
(unit: W)

length of conductor.

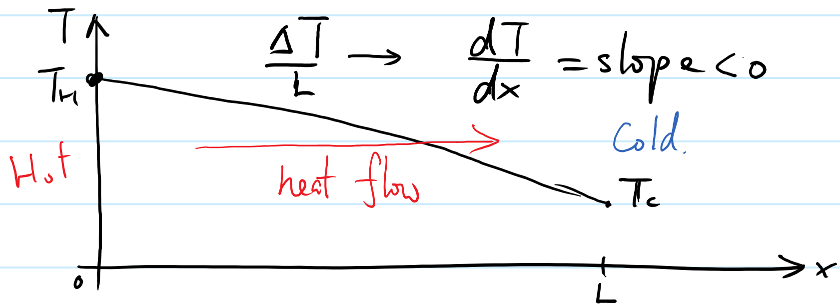
Thermal conductivity (material dependence), $\frac{W}{mK}$.

$$\frac{T_H - T_c}{L} = \frac{\Delta T}{L} = \text{Temp. gradient}, \text{ diff. in Temp. over distance}$$

Consider temperature as a function of x.



$$\frac{\Delta T}{L} \rightarrow \frac{dT}{dx} = \text{slope} < 0$$

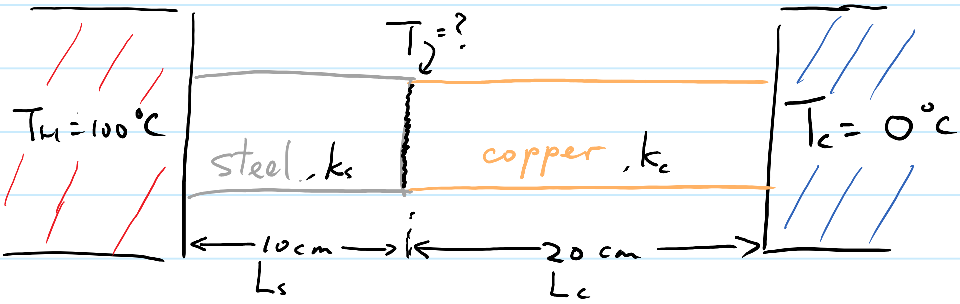


Since $\frac{dT}{dx}$ is opposite to the direction of the heat flow,

$$H \propto -\frac{dT}{dx}$$

Define $H > 0$ when heat flow to $+x$, $H = -kA\frac{dT}{dx}$

Example. conducting heat with two materials.



$k_s = 50.2$ W/mK , $k_c = 385.0$ W/mK

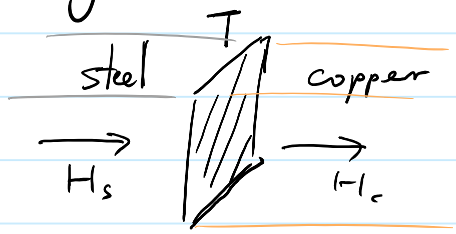
Find T.

Heat flow along the steel $= H_s = k_s A \frac{T_H - T}{L_s}$

Heat flow along the copper $= H_c = k_c A \frac{T - T_c}{L_c}$

At steady state, $H_s = H_c$ otherwise there is net heat flowing in or away at the boundary.

$\Rightarrow \quad H_s = H_c$

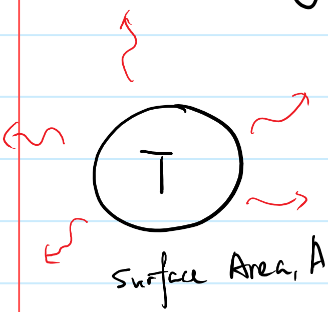


$$\Rightarrow \quad \frac{k_s}{L_s}(T_H - T) = \frac{k_c}{L_c}(T - T_c)$$

$$\Rightarrow \quad T = 20.7\ °C$$

Radiation

Any body ($T > 0\,K$) radiates energy.



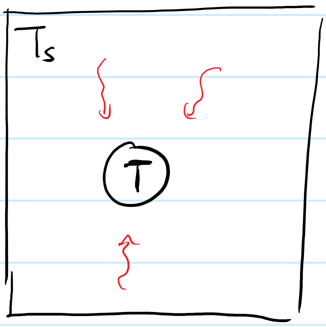
Radiation Power

$$H_{rad} = A e \sigma T^4 \quad [W]$$

σ = Stefan - Boltzmann Constant (universal)
$= 5.6704 \times 10^{-8}\ W/m^2/K^4$

e = emissivity of object. $0 \leq e \leq 1$

A = Total surface area.



The environment surrounding (T_s) the object also radiates. The object will absorb the radiation according to.

$$H_{abs} = A e \sigma T_s^4$$

$\Rightarrow$ The net heat flow due to radiation is

$$H_{net} = H_{rad} - H_{abs} = A e \sigma (T^4 - T_s^4)$$

Human body at $T = 30^\circ C$ with surface area $1.2\ m^2$ and emissivity $e \simeq 1$ surrounded by temperature $20^\circ C$.

$$H_{net} = A e \sigma (T^4 - T_s^4)$$
$$= (1.2)(1)(5.67 \times 10^{-8}) \cdot (303^4 - 293^4)$$
$$= 72\ W$$

i.e. The human needs to generate 72 W to keep the body temp.