Chapter 17: Temperature and Heat

- What is HEAT and what is TEMPERATURE?
- How do you change temperature/heat of a material?
- How do materials react when changing temperature? How to measure temperature?
- How to quantify “temperature”?
- How to quantify “heat”?
- How do heat transfer?

What is HEAT and what is TEMPERATURE?

- This stove is HOT.
- This stove generate HEAT.
- The refrigerator is COLD.
- The refrigerator extract HEAT from the food stored in it.

- Temperature is a quantitative measurement of hotness/coldness; while Heat is a form of energy that could alter the value of temperature.

How do you change temperature/heat of a material?

- What is “room temperature”?
- If you place a cup of hot water on table, what would be the temperature of it after couple hours?
- If you place a cup of iced tea on table, what would be the temperature of it after couple hours?

- Thermal equilibrium: a status that two objects reach the same temperature by exchanging heat.

Zeroth Law of Thermodynamics

If two separated systems/objects are each in thermal equilibrium with a third system/object simultaneously. All three systems/objects are in thermal equilibrium with each other, and thus all three have same temperature.

$$T_A = T_B = T_C$$

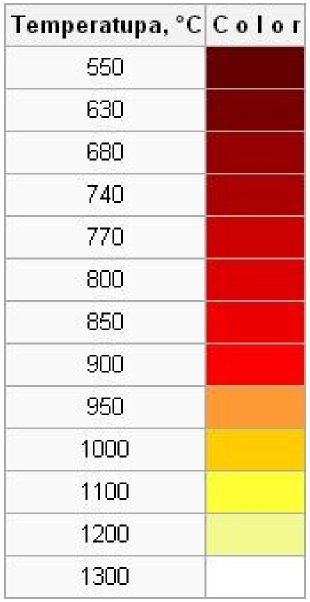
When reach thermal equilibrium

Note: Zeroth law of thermodynamics is the basis why thermometer works. Thermometer is, in fact, measuring its own temperature (will discussed later). With Zeroth law, we know that the measured temperature is also the temperature of the object that has thermal equilibrium with the thermometer.

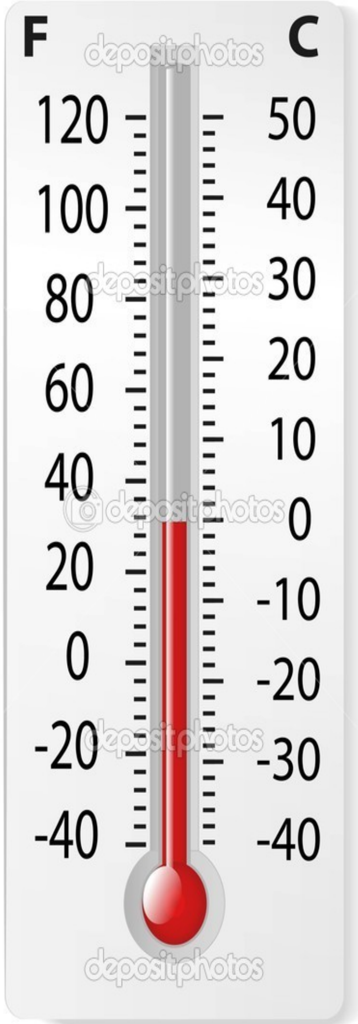
How do materials react when changing temperature?

How to measure temperature?

- Expansion/Contraction (change length/area/volume)
- Light emission



Temperatupa, °C	Color
550	🟥
630	🟥
680	🟥
740	🟥
770	🟥
800	🟥
850	🟥
900	🟥
950	🟧
1000	🟨
1100	🟨
1200	🟨
1300	⬜




Σ2
E0.98
14/08/08
11:12:29
RUN
S2.0
(100.0)
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
(-20.0)
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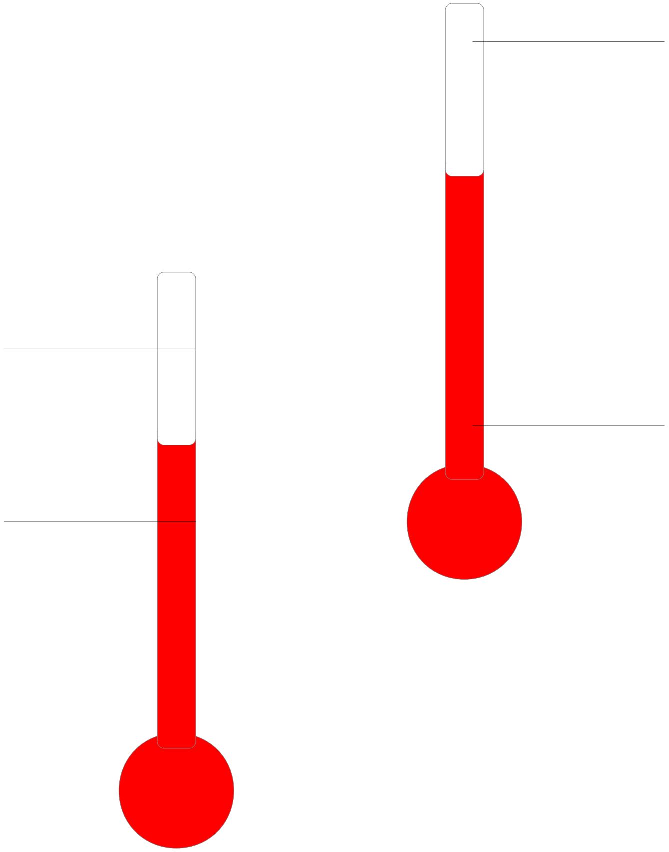
Max 33.8
NEC

How to quantify “temperature”?

Historically: ~ 18th century

Fahrenheit

Celsius



Vapor/Water = 100 °C

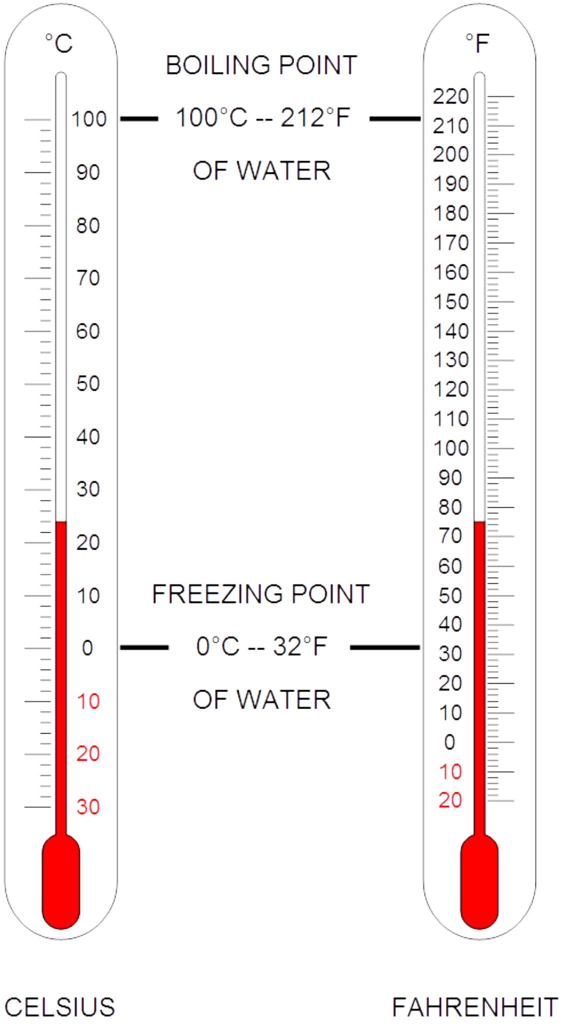
Human Body = 100 °F

Water/Ice = 0 °C

Ice + Salt = 0 °F

How to quantify “temperature”?

Both Fahrenheit and Celsius are linear scale, so their converting relationship should be a linear function



$$T_F = a T_C + b$$

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

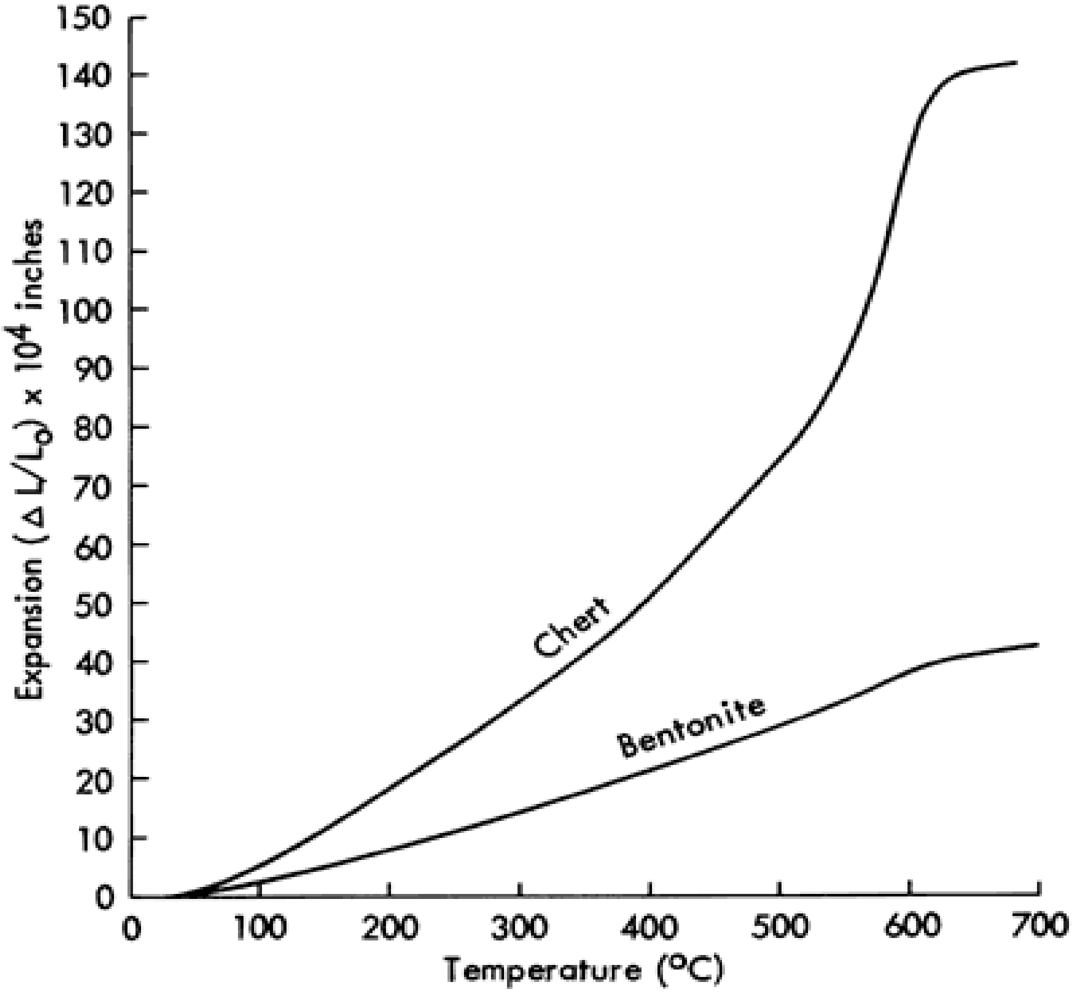
How to quantify “temperature”?

- For scientific purpose, Kelvin scale was developed.
- Kelvin scale is also named as “absolute temperature” scale

$$T_K = T_C + 273.15$$

How do materials react when changing temperature?

- Expansion/Contraction (change length)



Simplest model:
Local linear relationship

$$\frac{\Delta L}{L_0} = \alpha \Delta T$$

Practice:

A U.S. penny has a diameter of 1.9000 cm at 20.0 ◦C. The coin is made of a metal alloy (mostly zinc) for which the coefficient of linear expansion is $2.6\times10^{-5}K^{-1}$.

Part A

What would its diameter be on a hot day in Death Valley (49◦C)?

Part B

On a cold night in the mountains of Greenland (-50◦C)?

How do materials react when changing temperature?

- Expansion/Contraction (change volume)

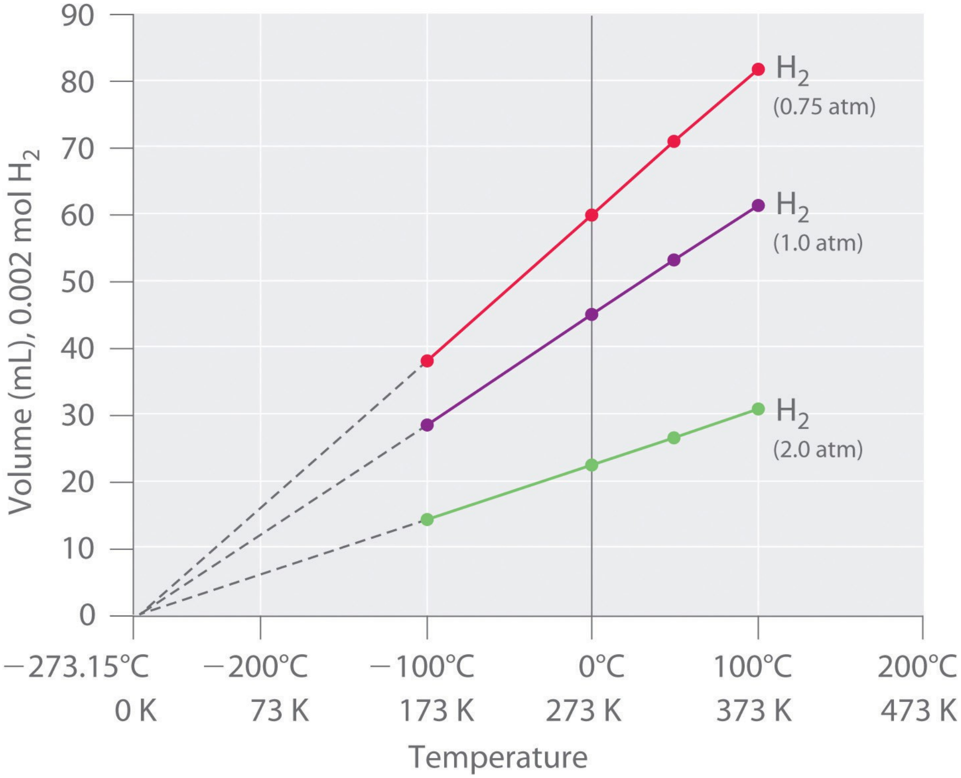
Simplest model:
Local linear relationship

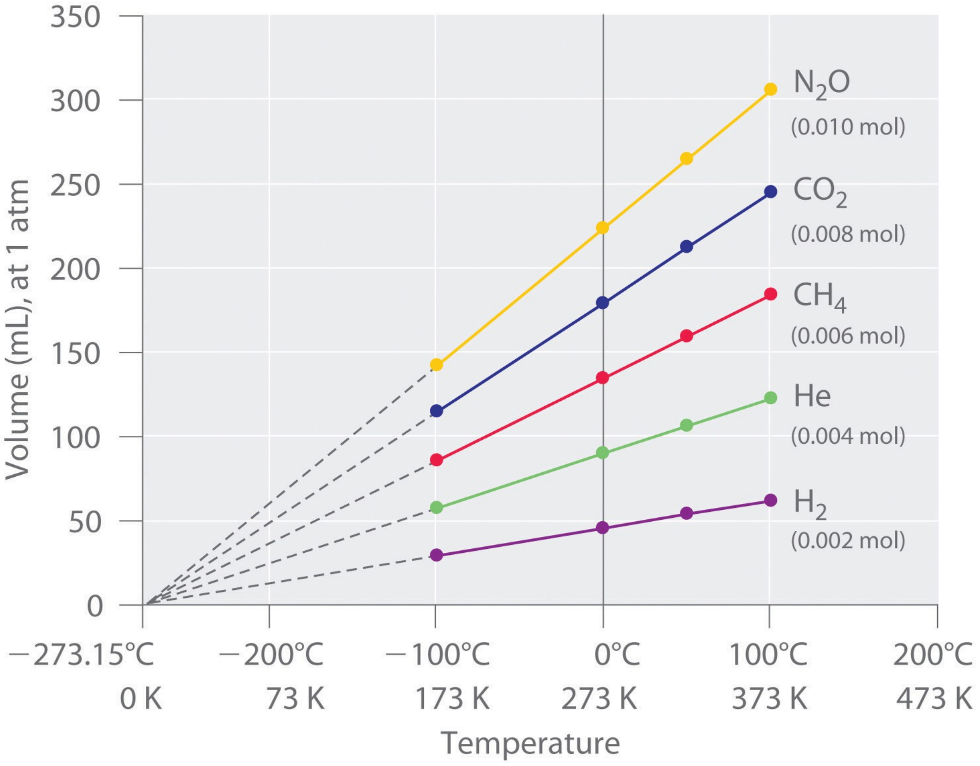
$$\frac{\Delta V}{V_0} = \beta \Delta T$$

$$\beta \approx 3 \alpha$$

How do materials react when changing temperature?

- Expansion/Contraction (gas): the need of Kelvin scale





$$\frac{T_2(K)}{T_1(K)} = \frac{p_2}{p_1}$$

How to quantify “heat”?

- Heat is a form of energy.

$$4.186\,J = 1\,cal$$

$$1\,Btu = 252\,cal = 1055\,J$$

- To reach thermal equilibrium: heat transfer from the high temperature object to the low temperature one.
- How much heat could raise 1 degree C?

How much heat could raise 1 degree C?

- It depends on material (type and amount).
- The easiness of the change of temperature is described by “specific heat” (how much heat is needed per kg of material to raise 1 K (or C).)

$$c=\frac{1}{m}\frac{dQ}{dT} \qquad \Rightarrow \qquad \Delta Q = m\,c\,\Delta T$$

- For water $c_{water}=4190\,\frac{J}{kg\cdot K}=1\,\frac{cal}{g\cdot {}^{o}C}$

How much heat could raise 1 degree C?

- “specific heat” (how much heat is needed per ***mole*** of material to raise 1 K (or C).)

$$C=\frac{1}{n}\frac{dQ}{dT} \quad \Rightarrow \quad \Delta Q = n C \Delta T$$

- For water

$$C_{water}=75.4\frac{J}{mol\cdot K}$$

Temperature change = heat flow?

- Is there any occasion that you add/extract heat from a substance and the temperature does not change?
- Ice/Water; Water/Vapor (Phase change)
- Latent Heat: L (how much heat per kg is needed to change phase)

$$\Delta Q = \Delta m \cdot L$$

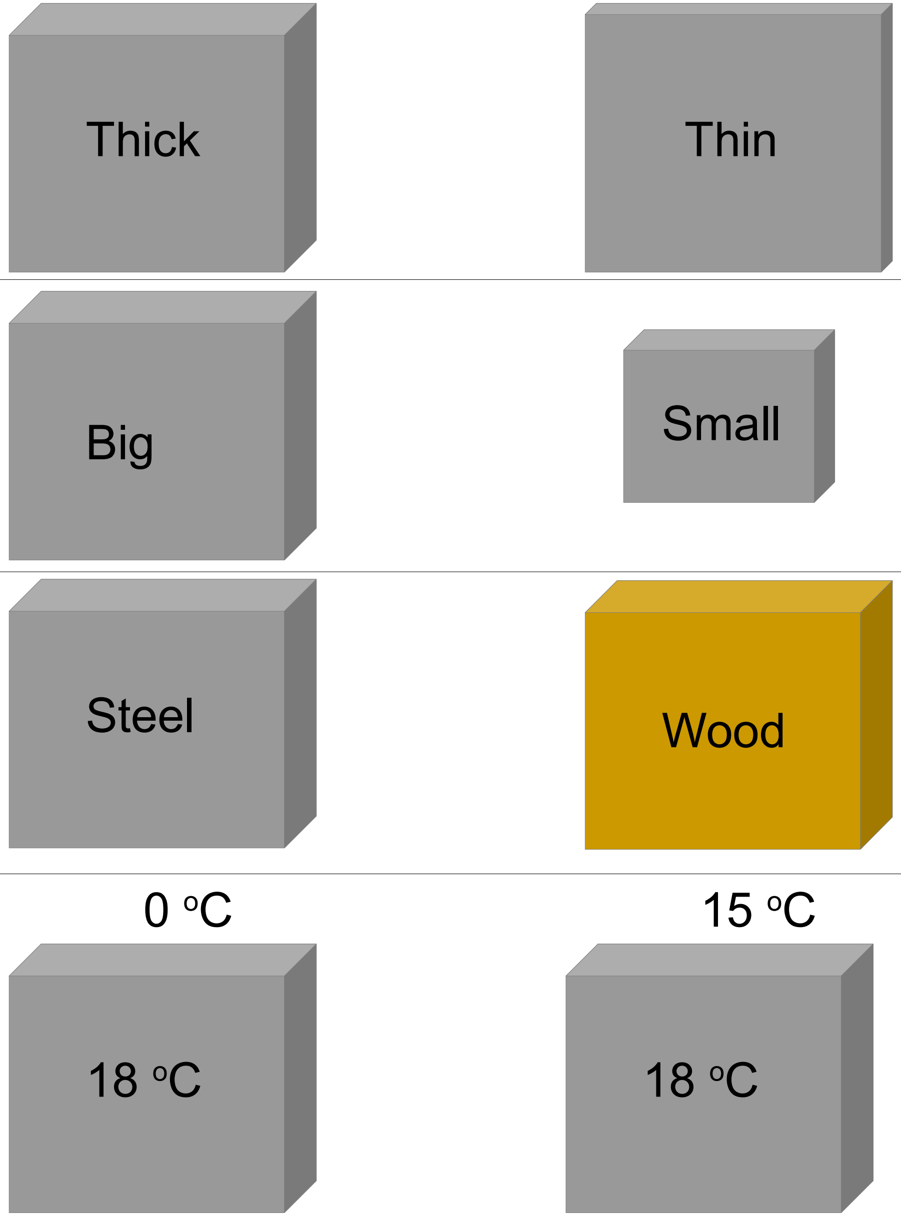
Heat added/extracted

Amount of substance (in mass)
that undergoes phase change

How do heat transfer?

- Conduction (through vibration (wave) of atoms in substance)
- Convection (through flow of media, such as liquid or gas)
- Radiation (through electromagnetic wave)

Conduction (Which transfer more heat/sec?)



Thick Thin

$$\frac{dQ}{dt} \propto \frac{1}{L}$$

Big Small

$$\frac{dQ}{dt} \propto A$$

Steel Wood

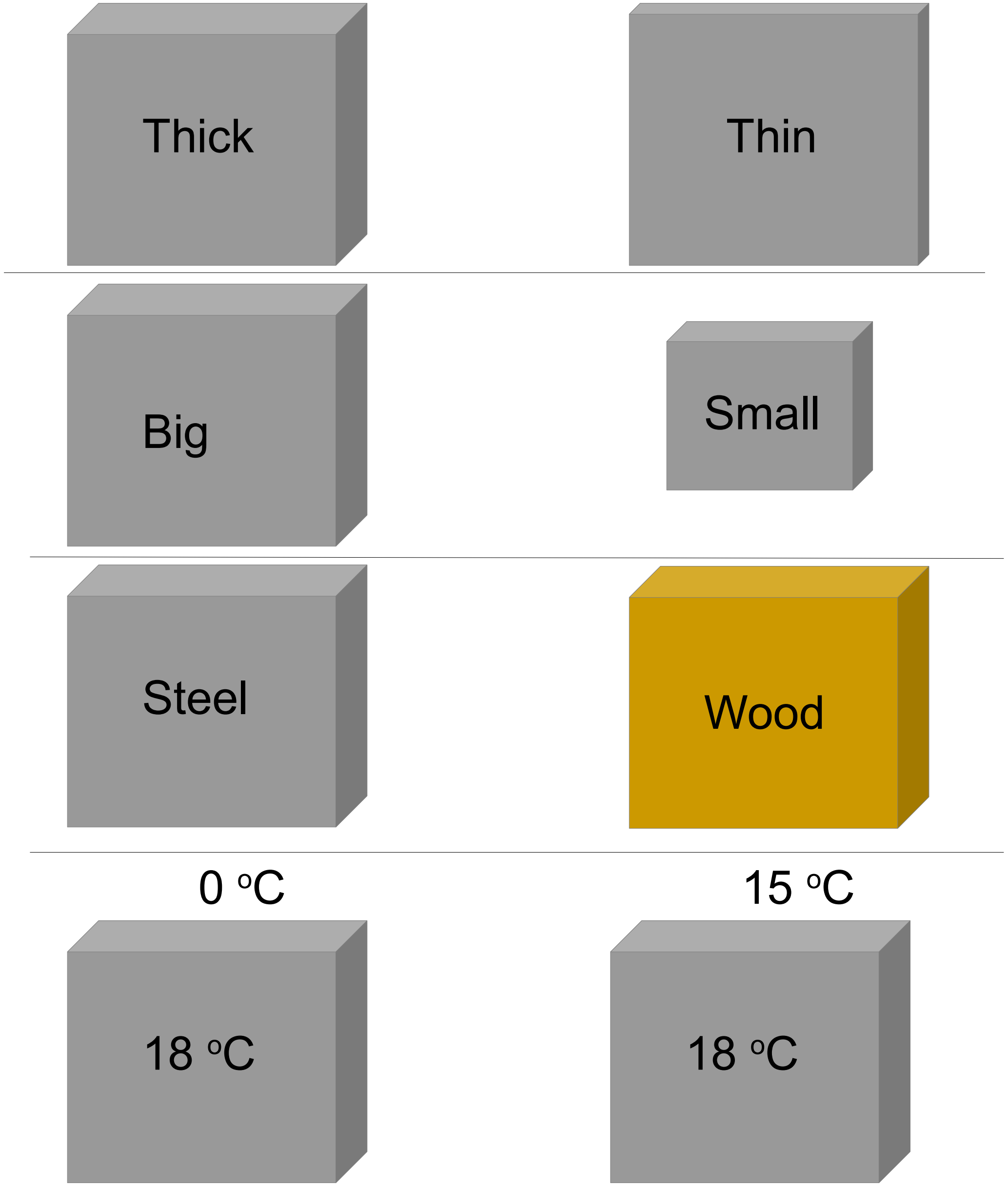
$$\frac{dQ}{dt} \propto k$$

0 °C 15 °C

18 °C 18 °C

$$\frac{dQ}{dt} \propto \Delta T$$

Conduction (Which transfer more heat/sec?)



Thick

Thin

Big

Small

Steel

Wood

0 °C

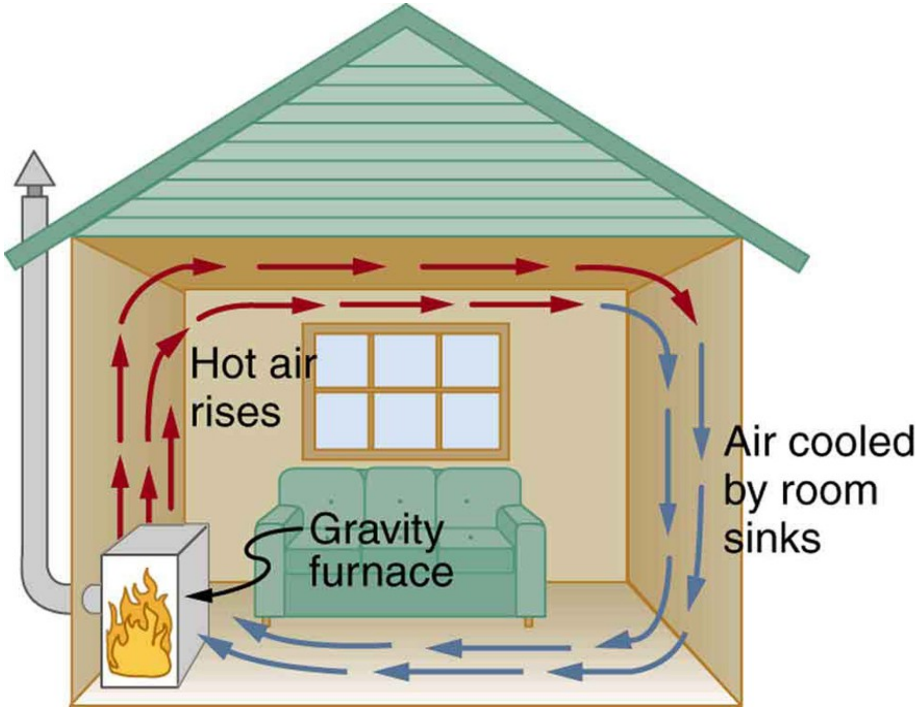
15 °C

18 °C

18 °C

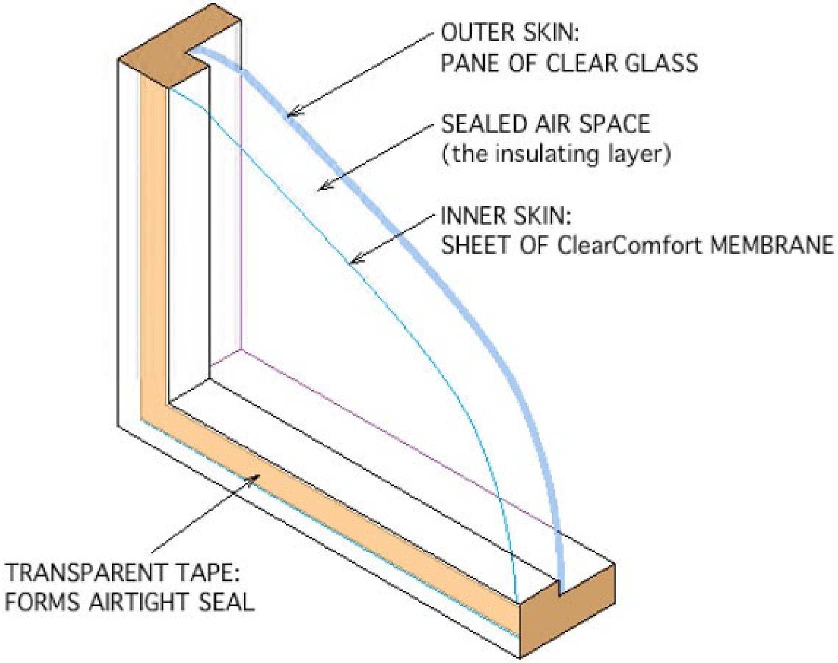
$$\frac{dQ}{dt} = k\,A\,\frac{\Delta T}{L}$$

Convection (through flow of media, such as liquid or gas)



- Can fluid (such as air or water) transfer heat through "conduction" (no mass flow)?

Convection (through flow of media, such as liquid or gas)



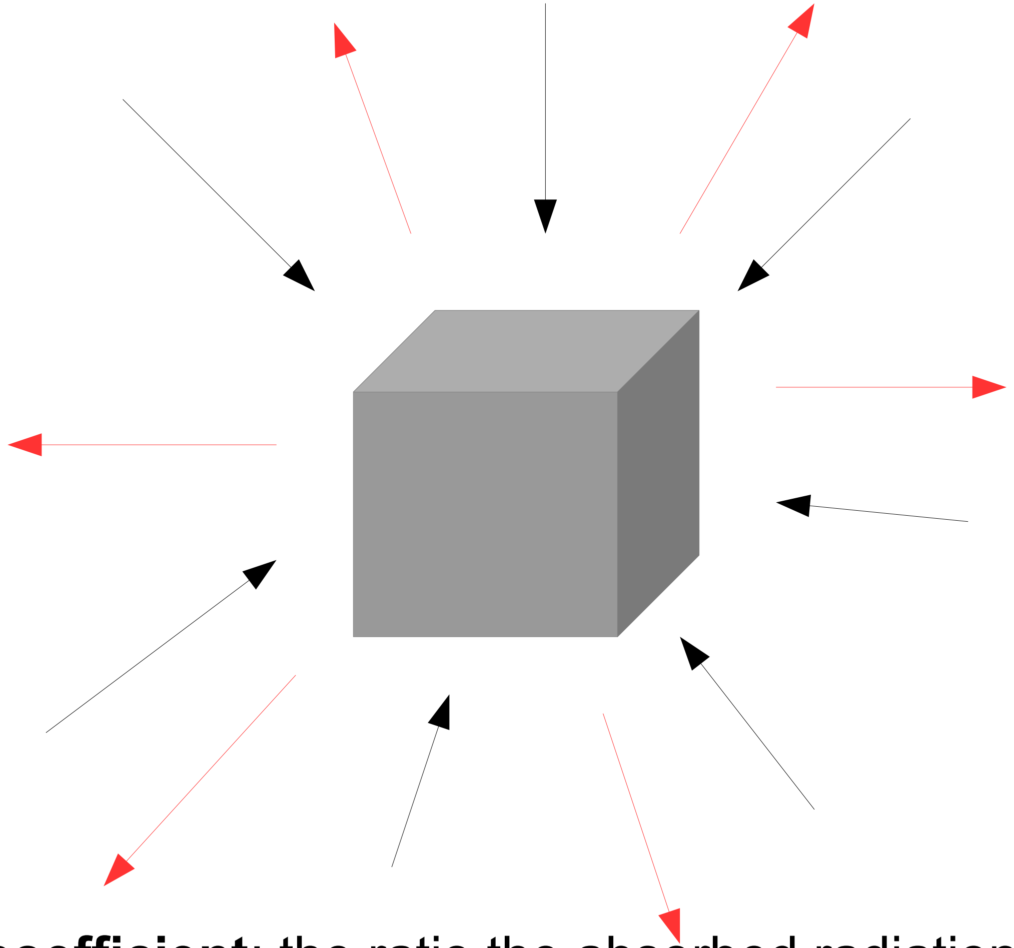
- Can fluid (such as air or water) transfer heat through "conduction" (no mass flow)?

Table 17.5 on page 571

$$k_{air} = 0.024\,W/m\cdot K$$

$$k_{wood} = 0.12 - 0.04\,W/m\cdot K$$

Radiation (absorption and emission)



- **Absorptivity coefficient**: the ratio the absorbed radiation compared to the incident amount. (Range from 0 to 1)
- **Emissivity coefficient**: the ratio the emitted radiation compared to the maximum possible emission amount. (Range from 0 to 1)

Emissivity coefficient = absorptivity coefficieny

Ideal Black body

Absorb all radiation; Emit the maximum possible radiation

Absorptivity coefficieny = 1 = Emissivity coefficient

Radiation power of an object depends on?

- Temperature of the object
- Surface area of the object
- Emissivity of the object

$$H = \frac{dQ}{dt} = Ae\sigma T^4$$

How do heat transfer?

- Conduction $$H = \frac{dQ}{dt} = kA\frac{T_H - T_L}{x_H - x_L} = kA\frac{\Delta T}{L}$$
- Convection (skip)
- Radiation $$H = \frac{dQ}{dt} = Ae\sigma T^4$$
- e: emissivity (range: 0 – 1), for Blackbody: 1

$$\sigma = 5.670400 \times 10^{-8}\, W/m^2 \cdot K^4$$