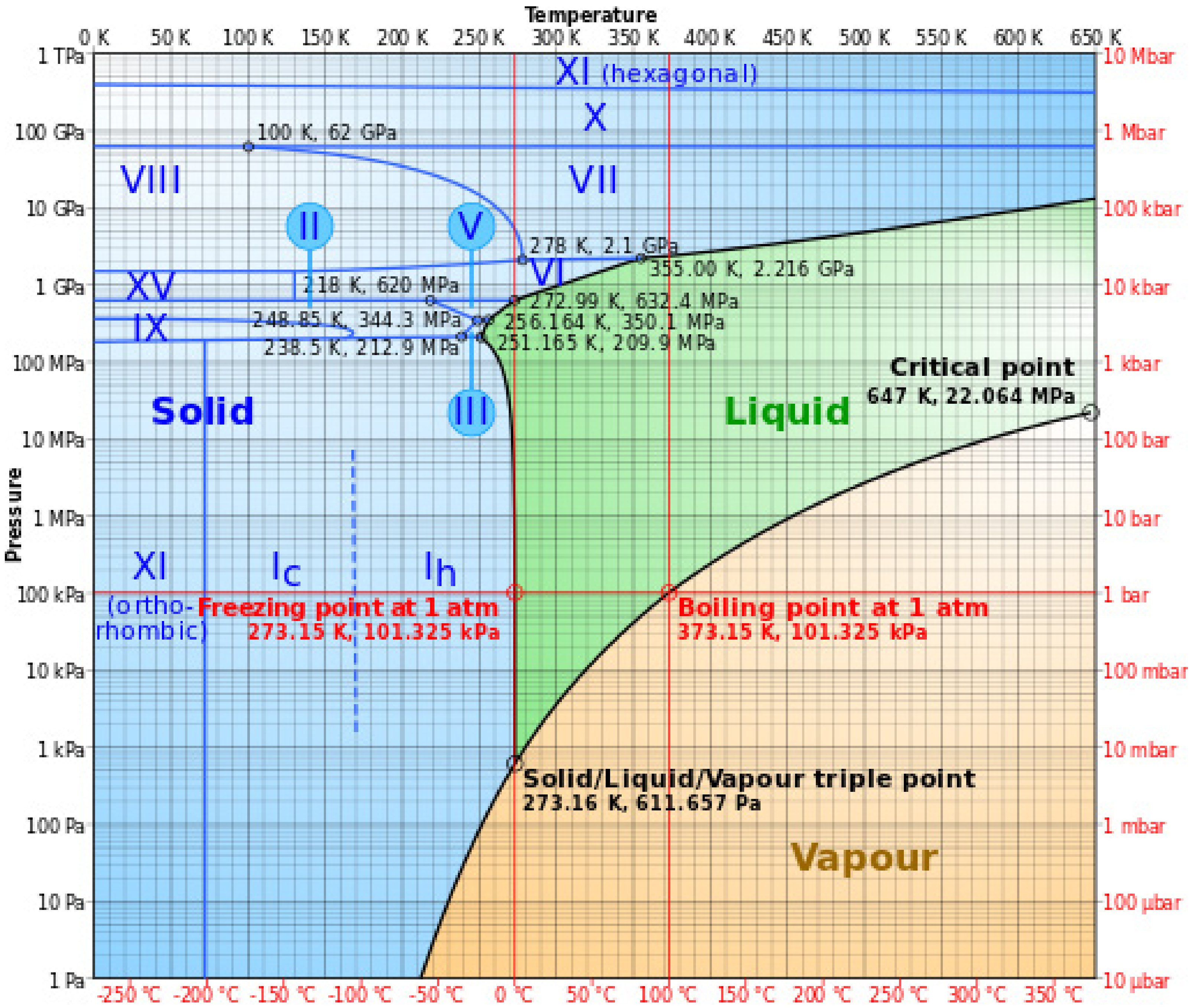
Introduction to Physics I

For Biologists, Geoscientists, & Pharmaceutical Scientists



Temperature
0 K
50 K
100 K
150 K
200 K
250 K
300 K
350 K
400 K
450 K
500 K
550 K
600 K
650 K
Pressure
1 TPa
100 GPa
10 GPa
1 GPa
100 MPa
10 MPa
1 MPa
100 kPa
10 kPa
1 kPa
100 Pa
10 Pa
1 Pa
10 Mbar
1 Mbar
100 kbar
10 kbar
1 kbar
100 bar
10 bar
1 bar
100 mbar
10 mbar
1 mbar
100 µbar
10 µbar
-250 °C
-200 °C
-150 °C
-100 °C
-50 °C
0 °C
50 °C
100 °C
150 °C
200 °C
250 °C
300 °C
350 °C
XI (hexagonal)
X
VII
VIII
100 K, 62 GPa
II
V
278 K, 2.1 GPa
355.00 K, 2.216 GPa
VI
XV
218 K, 620 MPa
272.99 K, 632.4 MPa
248.85 K, 344.3 MPa
256.164 K, 350.1 MPa
IX
238.5 K, 212.9 MPa
251.165 K, 209.9 MPa
Critical point
647 K, 22.064 MPa
Solid
III
Liquid
XI
Ic
Ih
(ortho-
rhombic)
Freezing point at 1 atm
273.15 K, 101.325 kPa
Boiling point at 1 atm
373.15 K, 101.325 kPa
Solid/Liquid/Vapour triple point
273.16 K, 611.657 Pa
Vapour

	Kelvin	Peak emittance wavelength[13] of black-body photons
Absolute zero (precisely by definition)	0 K	∞ [3]
Coldest measured temperature [14]	450 pK	6,400 kilometers
One millikelvin (precisely by definition)	0.001 K	2.897 77 meters (Radio, FM band)[15]
Cosmic Microwave Background Radiation	2.725 48(57) K	1.063 mm (peak wavelength)
Water's triple point (precisely by definition)	273.16 K	10,608.3 nm (Long wavelength I.R.)
Incandescent lamp[B]	2500 K	1160 nm (Near infrared)[C]
Sun's visible surface[C][16]	5778 K	501.5 nm (Green light)
Lightning bolt's channel	28,000 K	100 nm (Far Ultraviolet light)
Sun's core	16 MK	0.18 nm (X-rays)
Thermonuclear weapon (peak temperature)[17]	350 MK	8.3×10^{-3} nm (Gamma rays)
Sandia National Labs' Z machine [D][18]	2 GK	1.4×10^{-3} nm (Gamma rays)
Core of a high–mass star on its last day[19]	3 GK	1×10^{-3} nm (Gamma rays)
Merging binary neutron star system [20]	350 GK	8×10^{-6} nm (Gamma rays)
Gamma-ray burst progenitors[21]	1 TK	3×10^{-6} nm (Gamma rays)
Relativistic Heavy Ion Collider[22]	1 TK	3×10^{-6} nm (Gamma rays)
CERN's proton vs. nucleus collisions[23]	10 TK	3×10^{-7} nm (Gamma rays)
Universe 5.391×10^{-44} s after the Big Bang	1.417×10^{32} K	1.616×10^{-26} nm (Planck frequency)[24]

Material	Seebeck coefficient *relative to platinum* (μV/K)
Selenium	900
Tellurium	500
Silicon	440
Germanium	330
Antimony	47
Nichrome	25
Molybdenum	10
Cadmium, tungsten	7.5
Gold, silver, copper	6.5
Rhodium	6.0
Tantalum	4.5
Lead	4.0
Aluminium	3.5
Carbon	3.0
Mercury	0.6
Platinum	0 (definition)
Sodium	-2.0
Potassium	-9.0
Nickel	-15
Constantan	-35
Bismuth	-72

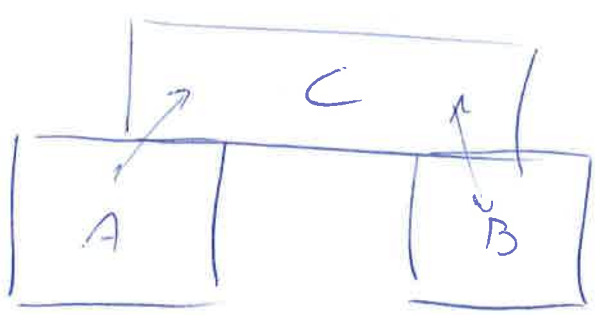
Thermodynamics

Heat and Temperature

- We all have an intuitive idea of temperature.
- In the next ~~lec~~ lectures we will define temperature and explain how to measure it. We will also define the concept of heat.
- Preview: Temperature is a measure of the average internal molecular kinetic energy of an object. Heat is the form of energy that causes this motion.

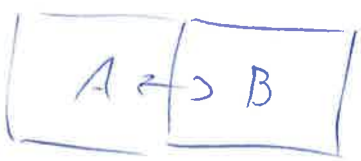
Zeroth Law of Thermodynamics

1.



~~A~~ A and B are in thermal contact with C, but not with each other. When A and B are in thermal equilibrium with C, they are in thermal equilibrium with each other.

2.



Note: 2 objects are in thermal equilibrium if they have the same temperature.

The above law is common sense, but there is no logical way to deduce this fact. Therefore we take it as an empirical law. This forms the basis for measuring and defining temperature.

Exp

Temperature Measurement

- How do we measure the macroscopic property of temperature without access to the microscopic (atomic) motion of molecules?

- We use the dependence of physical properties on temperature to create thermometers:

  - Volume of a fluid
  - Length of a rod
  - Pressure of a gas at constant volume

Any thermometric (temperature dependent) property can be use to establish (define) a temperature scale.

E.g. <u>Mercury thermometer</u>

↳ Glass bulb and tube containing fixed amount of mercury

- Place thermometer in ice water at atmospheric pressure → bring into thermal equilibrium.
- Mark the height of the mercury column as 0 °C.
- Place thermometer in boiling water at atmospheric pressure → bring into thermal equilibrium.
- Mark the height of the mercury column as 100 °C.
- Divide the height between the two marks in 100 divisions, each for 1 °C.

→ Thermometer!

Definition of Kelvin Scale

Kelvin → [K] SI unit for temperature

- Defined using <u>triple point</u> of water which is much more precisely reproducible than the melting or boiling point. Triple point is the unique temperature and pressure where water, water vapor, and ice coexist in equilibrium

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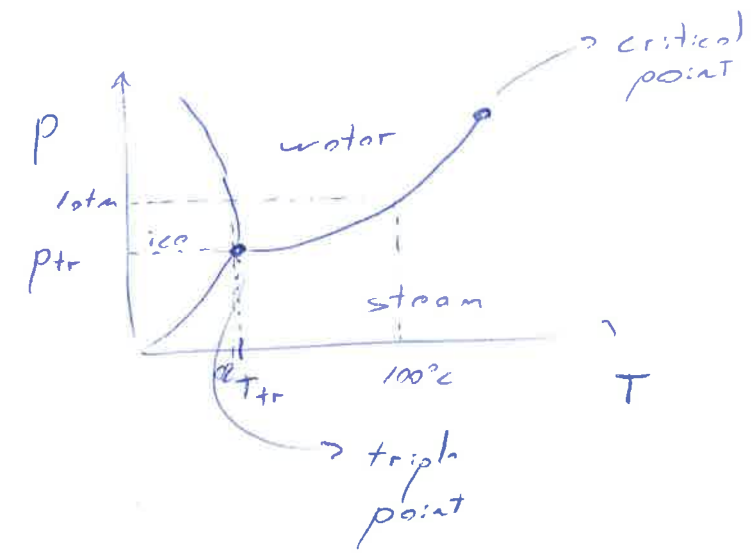


Definition

triple point temp. → $T_{tr} = 273.16\ K$

absolute zero temp. → $T_0 = 0\ K$
(no motion whatsoever)

(show K temperatures)

Celsius Scale

0 °C = temperature of melting ice

100 °C = temperature of boiling water

both at $p = 1.01325 \cdot 10^5$ Pa = 1.01325 bar

= 1 atm

$$T_K = T_{°C} + 273.15\ K$$

$$\Delta T_K = \Delta T_{°C}$$

$$T_{°C} = T_K - 273.15\ K$$

Exp: gas thermometers

Gas Thermometers

- Volume thermometer

$$V \propto T$$

← Volume of gas is proportional to the temperature at a constant pressure

(Charles's Law)

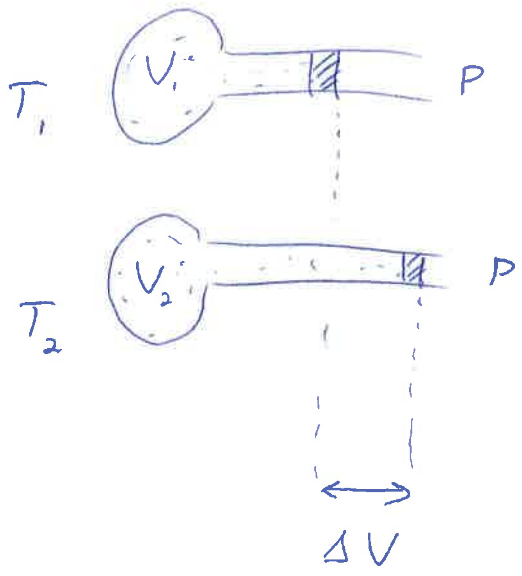
V ↗ volume

T ↗ temperature

$$\frac{V}{T} = k_V$$

k_V → constant

$$T = \frac{V}{k_V}$$



Constant pressure P

Exp: Fluid Thermometer

• Pressure Thermometer

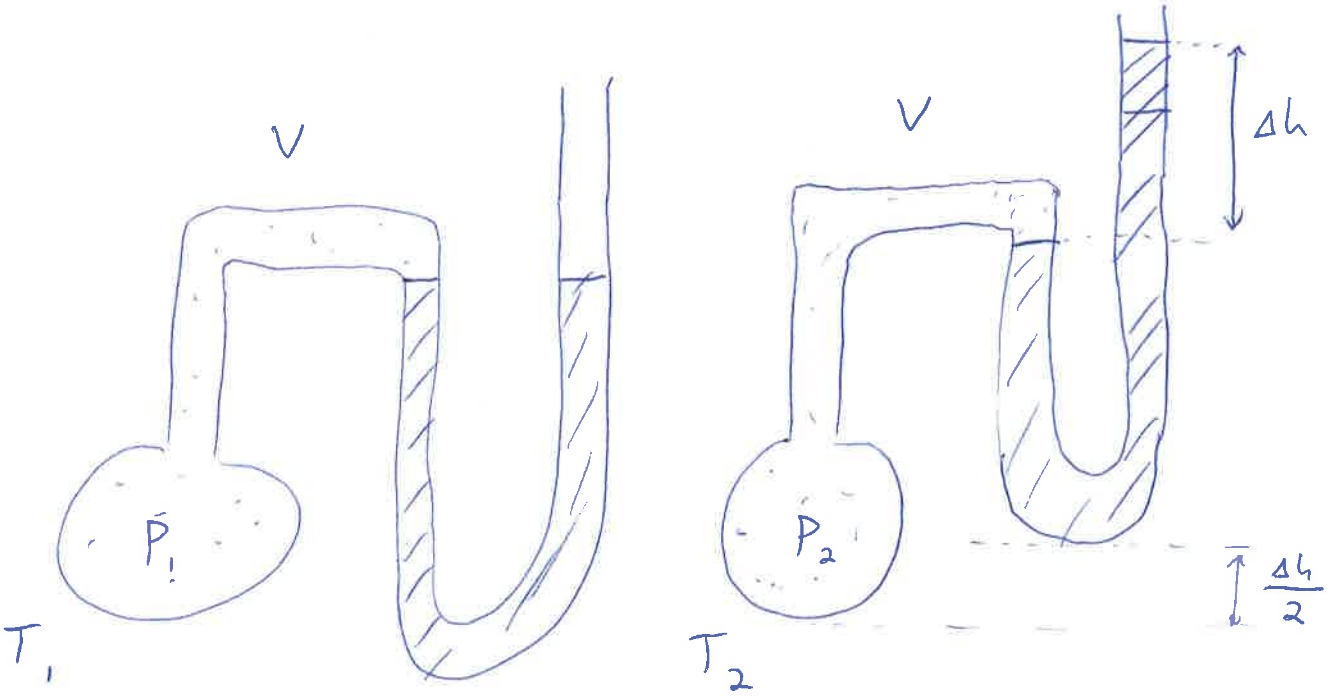
$$p \propto T$$

p ← pressure, T ← temperature

← Pressure of a gas is proportional to the temperature at a constant volume.

$$\frac{p}{T} = k_p \leftarrow \text{constant}$$

$$T = \frac{p}{k_p}$$



$$\Delta h \propto \Delta P = P_2 - P_1 \propto \Delta T$$

$$\Longrightarrow \Delta h \propto \Delta T$$

[Exp: Gas Thermometer]

Thermocouple Thermometer

- Seebeck Effect

$$U = \alpha \cdot \Delta T$$

voltage → U; α → Seebeck coefficient

$\alpha \approx 10\,\mu V/K$

materials constant

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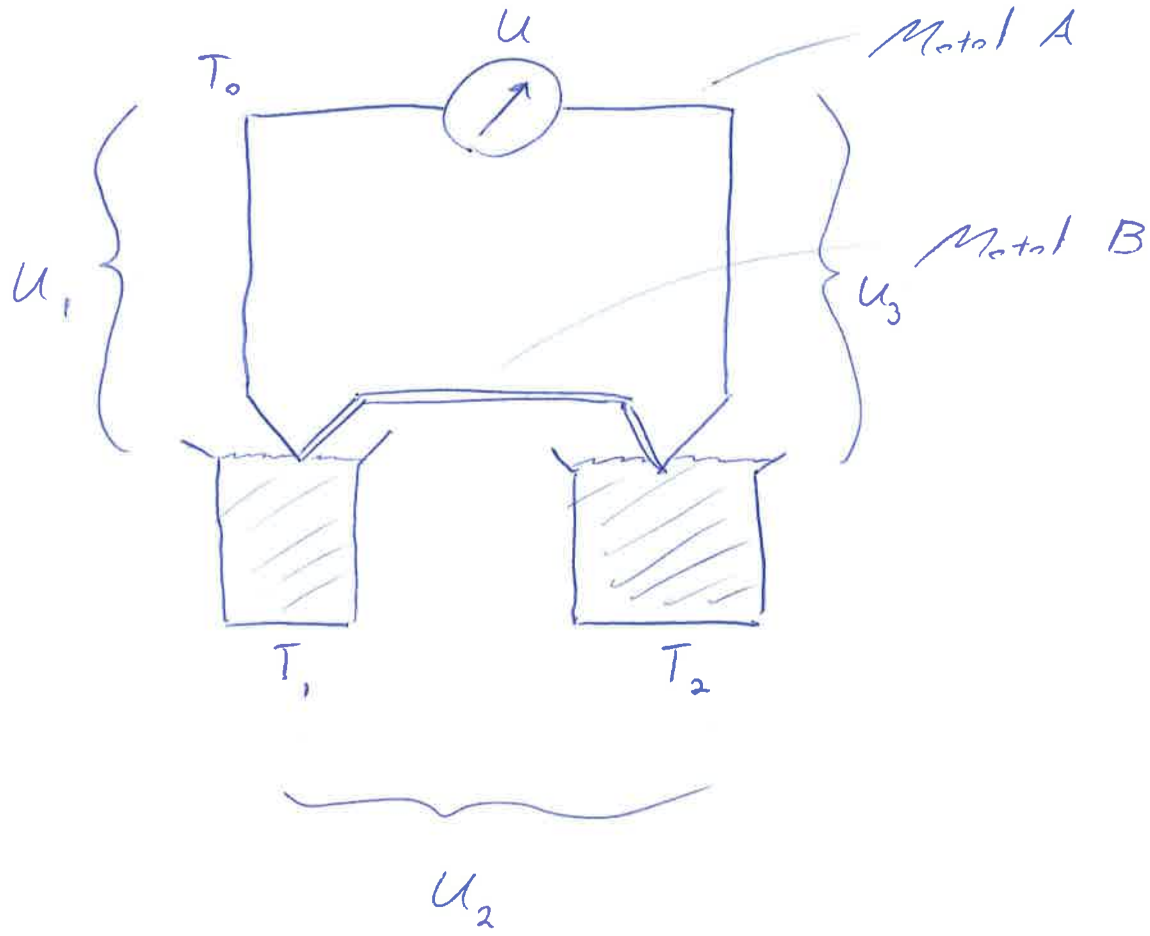


$$U = U_1 + U_2 + U_3$$

$$U_1 = \alpha_A (T_0 - T_1)$$

$$U_2 = \alpha_B (T_1 - T_2)$$

$$U_3 = \alpha_A (T_2 - T_0)$$

$$U = \alpha_A (T_0 - T_1 + T_2 - T_0) + \alpha_B (T_1 - T_2)$$

$$U = \alpha_A (T_2 - T_1) - \alpha_B (T_2 - T_1)$$

$$U = (\alpha_A - \alpha_B)(T_2 - T_1)$$

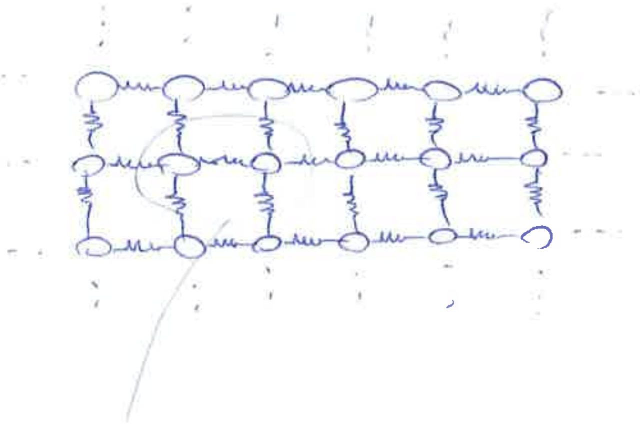
Note: for $\alpha_A = \alpha_B$, $U = 0$.

Using two different metals one can find a voltage proportional to the temperature difference of the two junctions.

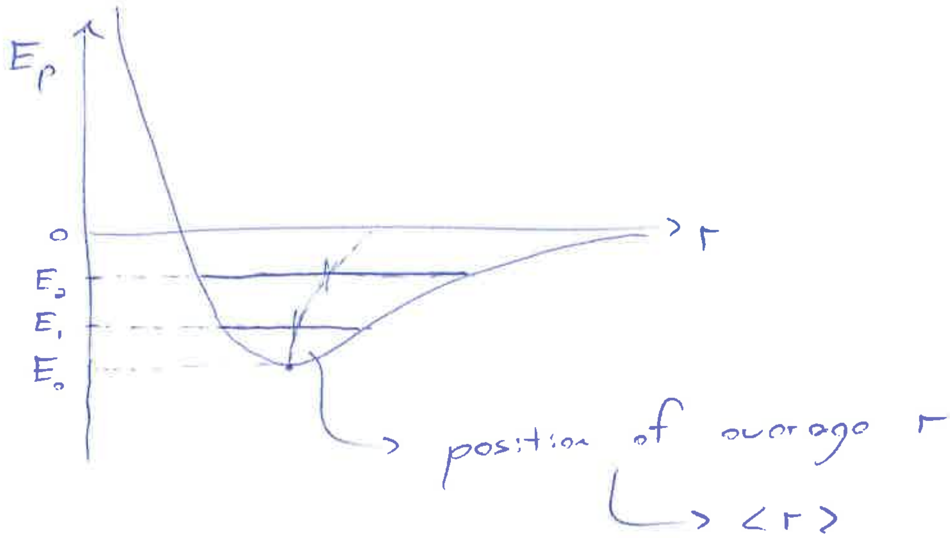
Exp: Thermocouple

Thermal Expansion

- Microscopic picture



O-ww-O Potential Energy describing bond between two atoms



$T_0 \rightarrow E_0$

$T_1 \rightarrow E_1$

$T_2 \rightarrow E_2$

$E_0 = E_p + E_k$

$E_k = 0$

$E_1 = E_p + E_k$

$E_k \geq 0$

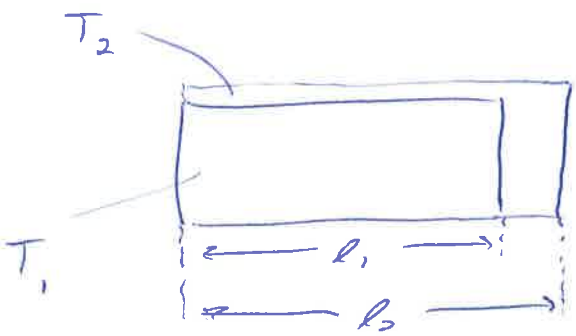
$E_2 = E_p + E_k$

$E_k \geq 0$

$\langle r \rangle$ gets larger with increasing microscopic kinetic energy. This means that $\langle r \rangle$ will increase with temperature.

↳ Macroscopic result: if each atom grows farther apart w/ increasing temperature, the solid will expand w/ increasing temperature.

· Macroscopic Picture



$$l_2 - l_1 = \Delta l$$

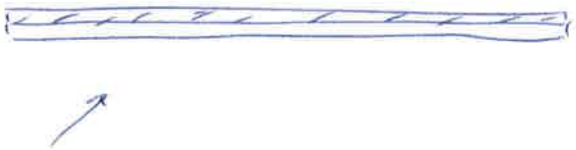
$$T_2 - T_1 = \Delta T$$

$$\frac{\Delta l}{l} = \alpha_l \cdot \Delta T$$

↳ α_l: coefficient of linear thermal expansion $\left[\frac{1}{K}\right]$

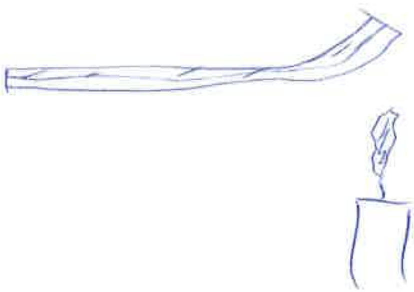
(show slide of coefficients)

Bi-metal Thermometer

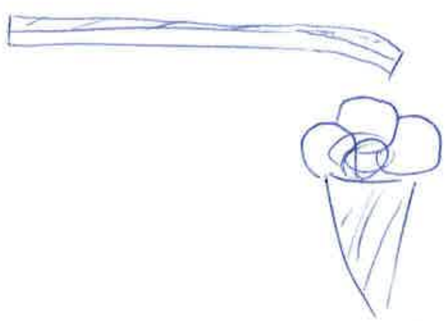


Strip of two metals w/ two different coefficients of linear thermal expansion.

Upon heating or cooling, the two strips will expand differently and therefore the bi-metal strip will bend.



hot



cold

Exp: bi-metal strip
Exp: spring thermometer

Exp: Infra-red Camera to see temperature