PHYS1901 Thermal physics

Lecture 1

A/Prof Boris Kuhlmey
School of Physics

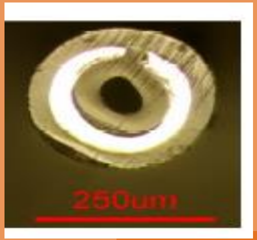
FACULTY OF SCIENCE

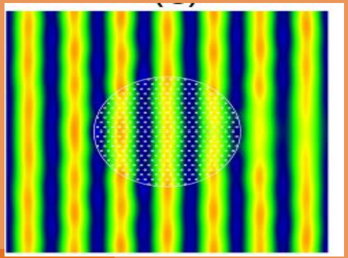
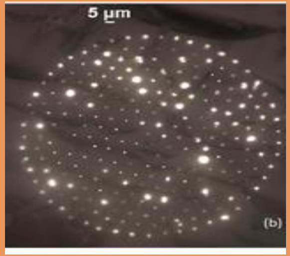
THE UNIVERSITY OF SYDNEY

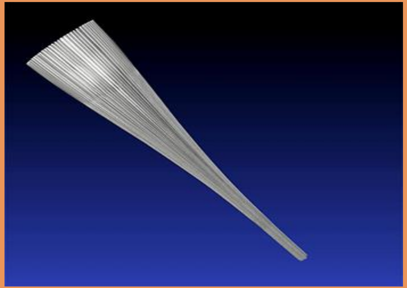
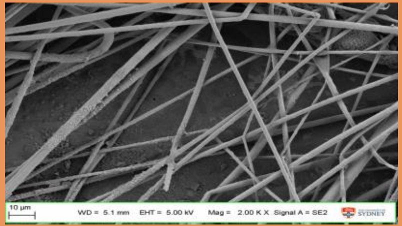
My research:

Photonics and Metamaterials – structured matter for artificial properties, by design

- Designer electromagnetic properties
- Invisibility
- lenses for the invisible
- Fabrication using drawing techniques (lots of thermal physics there!)
- Applications in photonics on a chip (CUDOS)



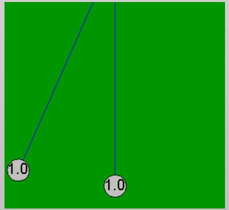



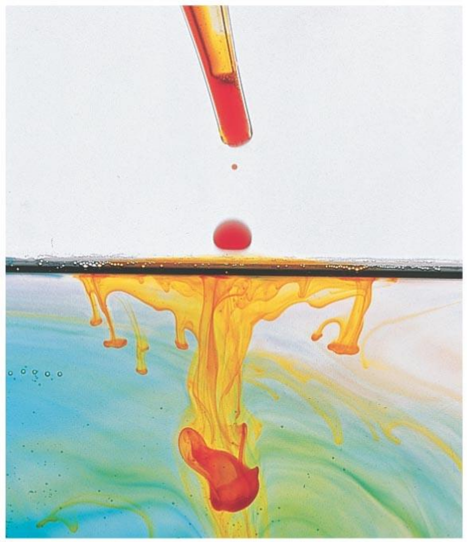
THE UNIVERSITY OF SYDNEY

A/Prof Boris Kuhlmey
boris.kuhlmey@sydney.edu.au
Room 317

cs

- Fundamental science
- Irreversibility
- Joining microscopic and macrosopic





Resources and format

- **Textbook:** Young & Friedman
- **Lectures**: Mon, Wed, Thu 2pm, Messel, 18 April – 8 June 2017

- **Assignments** due by 7pm Friday 26 May (#5) & 2 June (#6)
- **Web Resources:** see eLearning for links to PHYS1901
- Outline, Module Outline, Lecture Notes, Recordings, Muddiest Point
- Mastering Physics.

Thermal physics - outline

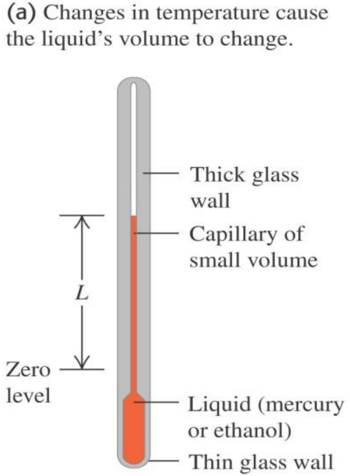
Lecture plan:

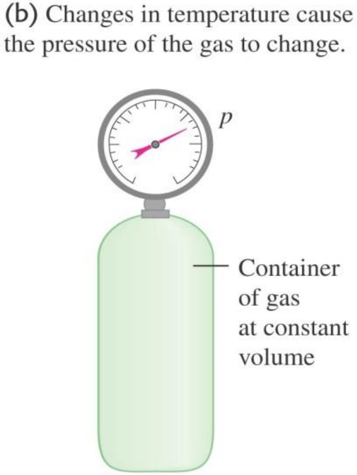
- **Text** : Young & Freedman.
- **Lec. 1.** Temperature and Heat Expansion: §17-1 – §17-4
- **Lec. 2.** Heat: §17-5 – §17-6
- **Lec. 3.** Methods of Heat Transfer: §17-7
- **Lec. 4.** Thermal Properties of Matter: §18-1 – §18-5
- **Lec. 5.** Work in Thermodynamics: §19-1 – §19-3
- **Lec. 6.** 1st Law of Thermodynamics: §19-4 – §19-6
- **Lec. 7.** Thermodynamics of an Ideal Gas: §19-7 – §19-8
- **Lec. 8.** Engines: §20-1 – §20-4
- **Lec. 9.** 2nd Law of Thermodynamics: §20-5 – §20-6
- **Lec. 10.** Entropy: §20-7 – §20-8

Temperature

- How would you define the temperature?

Temperature, T, is a measure of how ”hot” or ”cold” something is; this *depends* on how much “microscopic energy” it contains.





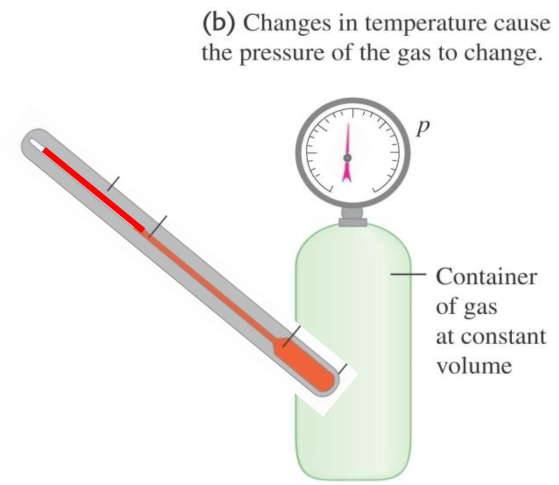
- Any physical property that depends on T (e.g. L or p) can be used in a thermometer
- A thermometer measures *its own temperature*

Temperature

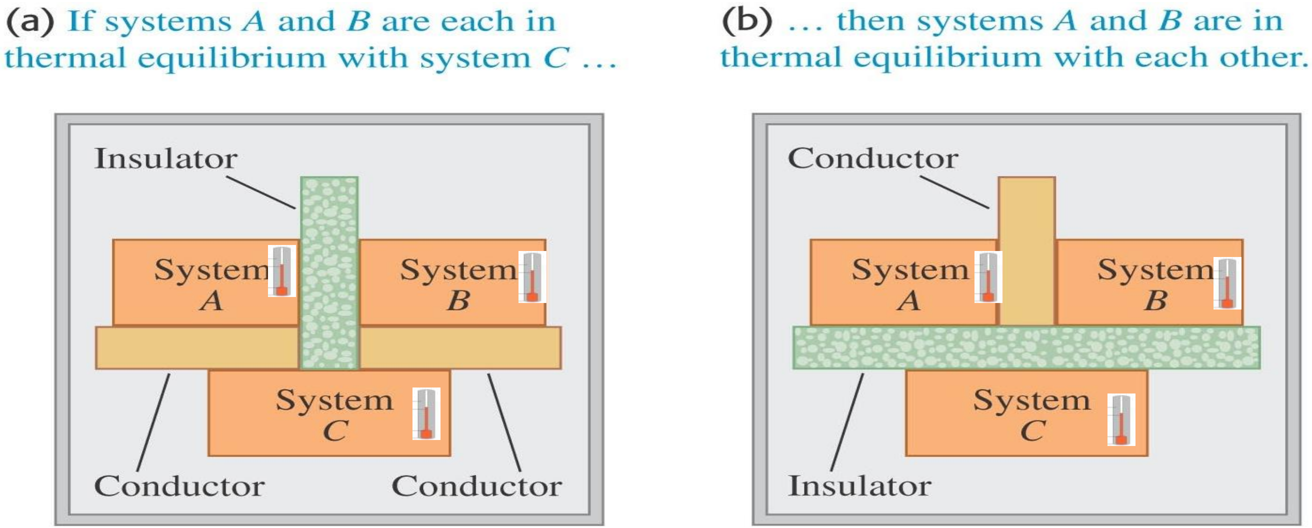
- How would you define the temperature?
- What does it mean if two objects have the same temperature?

Thermal equilibrium

Two thermometers in contact
First – reading change (heat flows)
Eventually – readings stabilize
Thermal equilibrium is reached
(no more heat flow)



Thermal equilibrium



“Zeroth law of thermodynamics”

Systems in thermal equilibrium have same temperature

If $T_A = T_C$ and $T_B = T_C$ then $T_A = T_B$

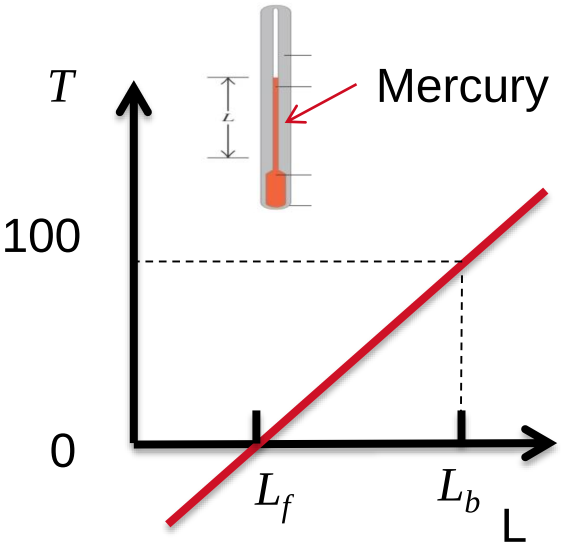
Temperature

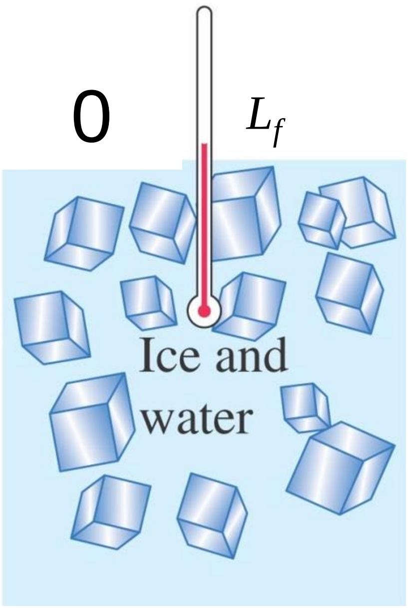
- How would you define the temperature?

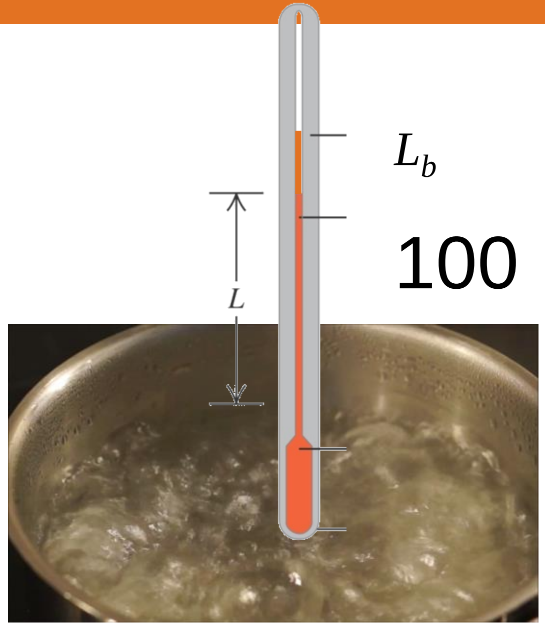
Two systems having the same temperature = they are in thermal equilibrium
A given temperature is a class of equivalence of objects in thermal equilibrium

- How would you define a temperature scale?

Defining a temperature scale



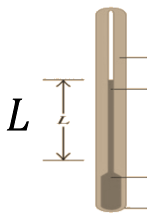


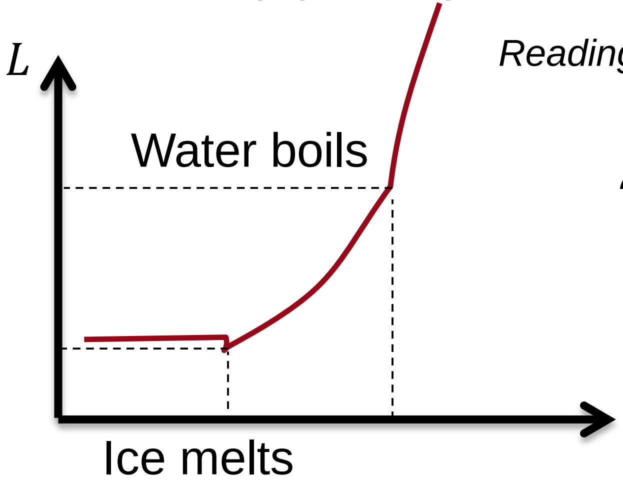


(original) Celsius temperature scale

Defining temperature scales

Reading thermometer 2 (eg water)

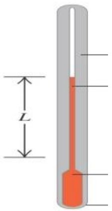




Reading at thermal equilibrium

?

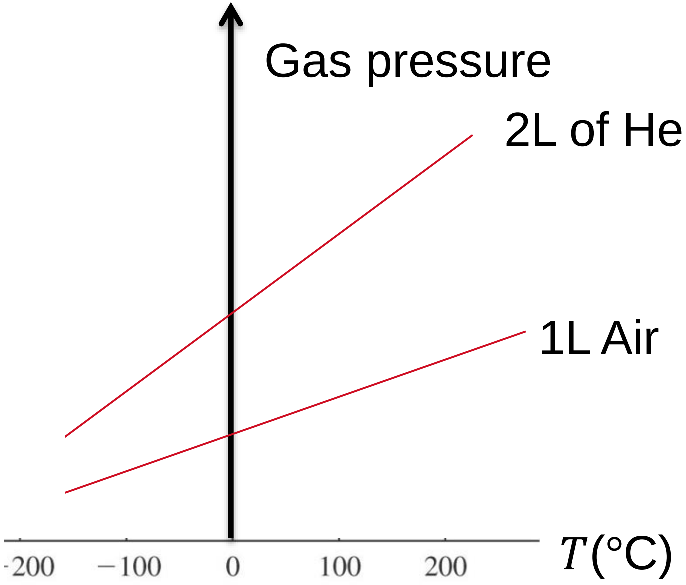
Reading thermometer 1



Definition of temperature scale seems arbitrary – and thermometer dependent!

Constant volume gas thermometer

(a) A constant-volume gas thermometer



Absolute temperature scale

Gas thermometer:

$$p = aT + b$$

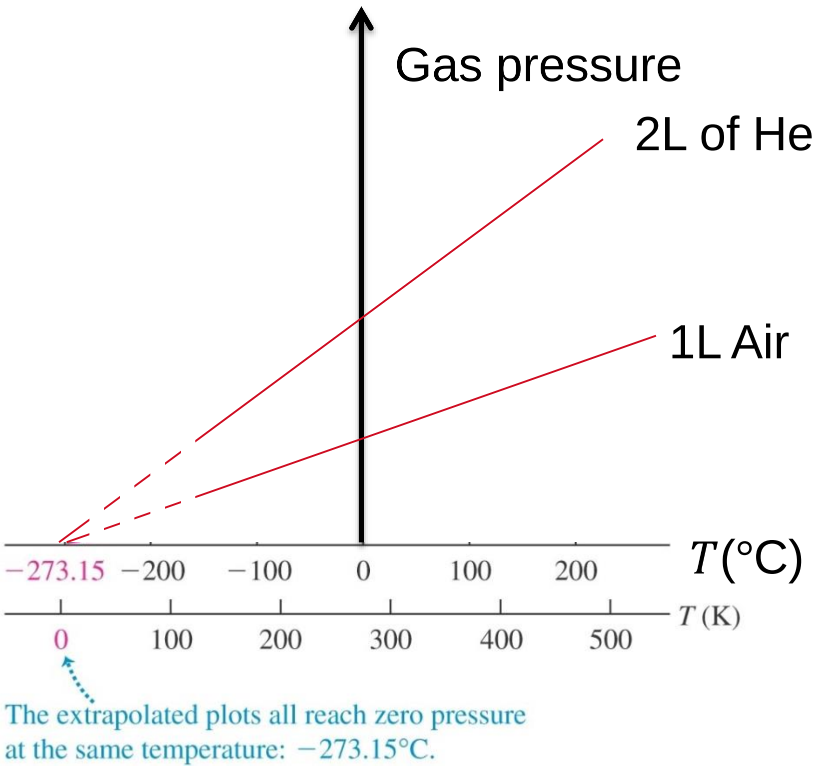
Slope a depends on details of the thermometer

Define new scale by

1. setting $b = 0$

   Now $T = \frac{p}{a}$ (but a still depends on thermometer)

2. With a single calibration point we define slope a to define full T scale

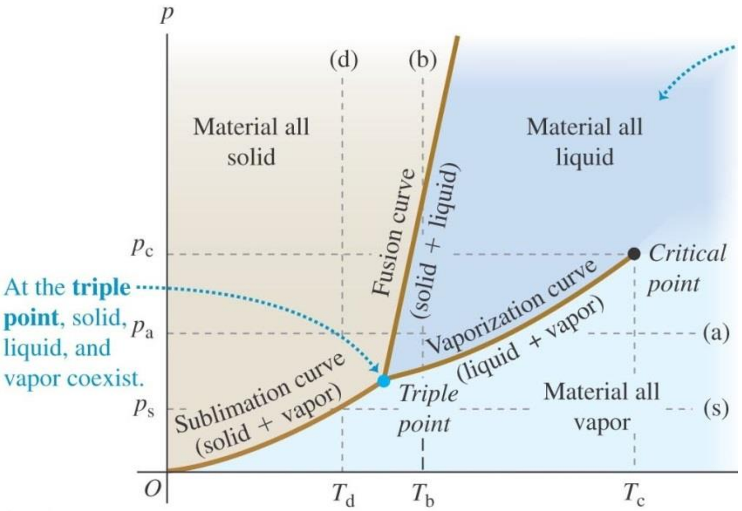


The Kelvin scale

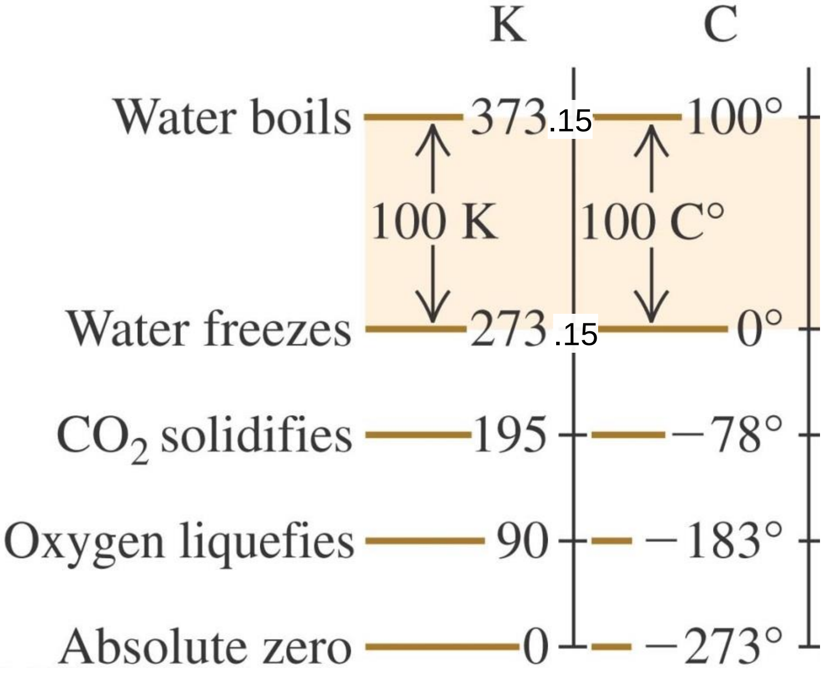
We define $T \equiv$ **273.16** K at triple point of water
$(T_{triple} \equiv 273.16\text{K} = 0.01°\text{C}$
$p_{triple} = 610\text{Pa}, 0.006\text{ atm}$

Kelvin temperature scale:
$$T(\text{K}) = T(°\text{C}) + \mathbf{273.15}\text{ K}$$
0 K = absolute zero

Kelvin =SI unit of temperature



Kelvin vs Celsius scales



Temperature summary

Definition:

Two systems having the same temperature = they are in thermal equilibrium
A given temperature is a class of equivalence of objects in thermal equilibrium

Scale:

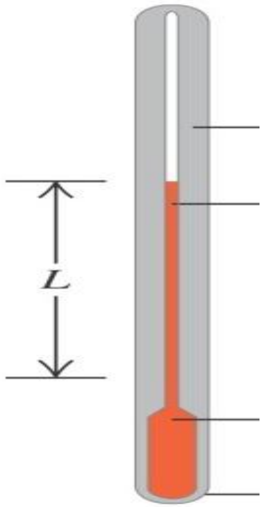
A good standard thermometer: Constant volume gas thermometer

Absolute temperature: Kelvin scale for temperature:

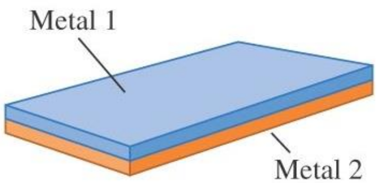
$T = 0\ K$ at absolute zero

$T = 273.16\ K$ at water's triple point

Thermal expansion



(a) A bimetallic strip



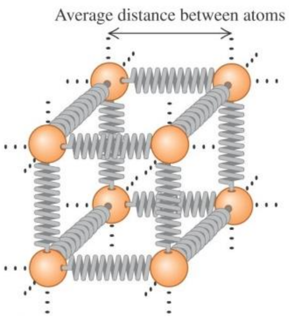
(c) A bimetallic strip used in a thermometer

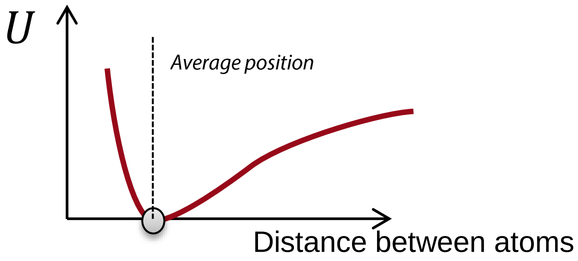
But why do liquids, metals expand?

Expansion

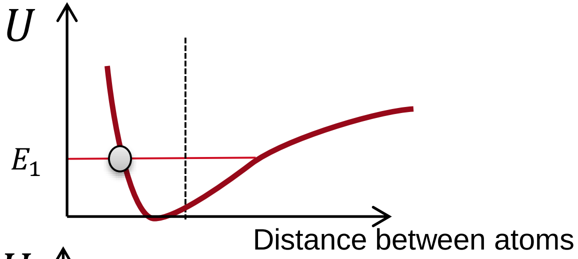
Higher temperature = more energy per atom

Energy of atom E=
Potential spring energy U
+
Kinetic energy K

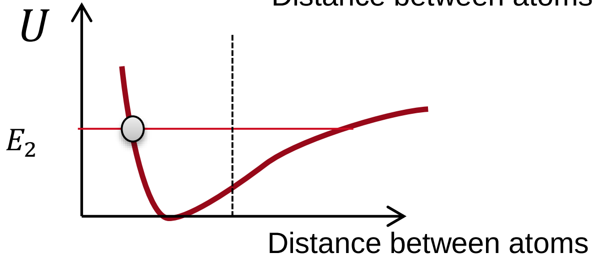




$E = U = K = 0$



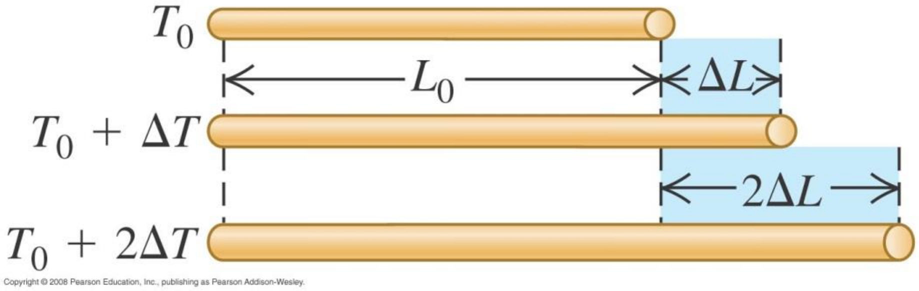
$E_1 > 0$



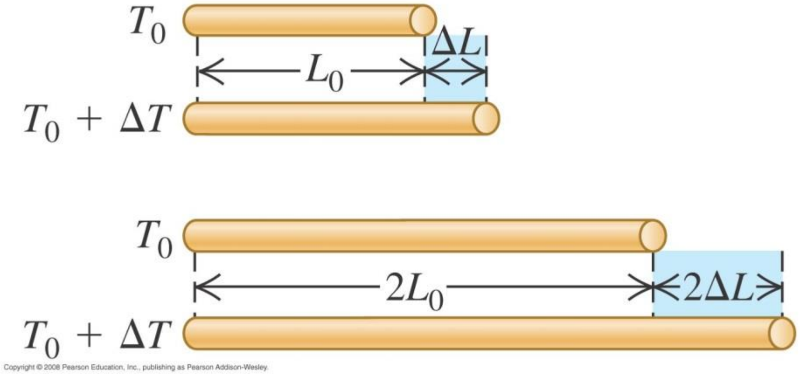
$E_2 > 0$

Coefficient of linear expansion

(a) For moderate temperature changes, ΔL is directly proportional to ΔT.



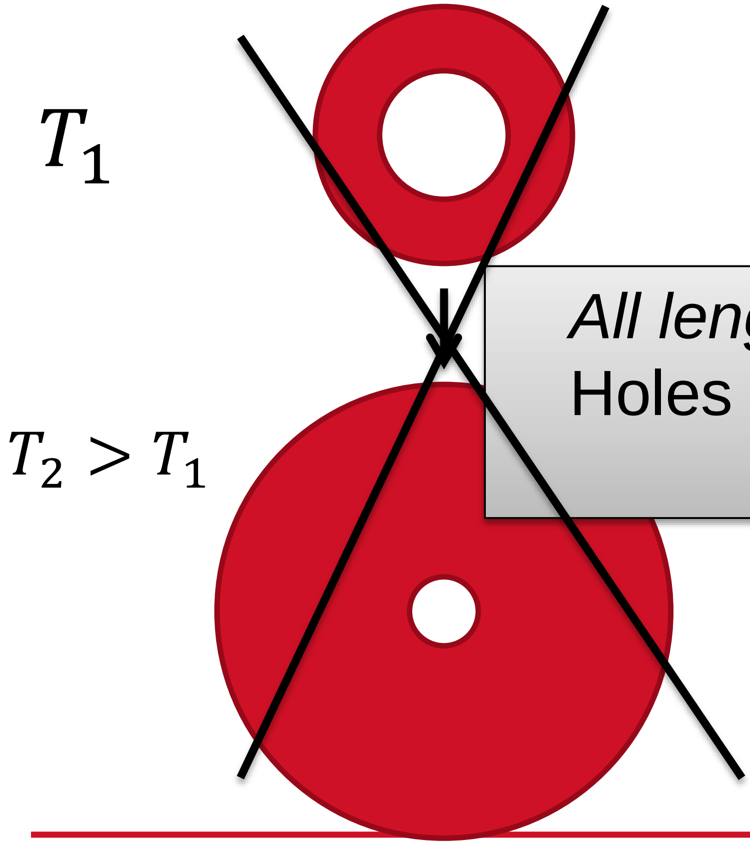
(b) ΔL is also directly proportional to L_0.



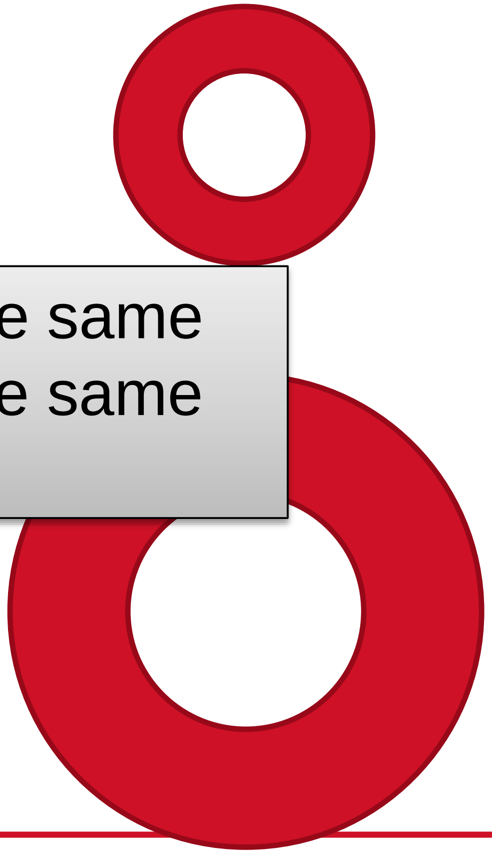
$$\boxed{\Delta L = \alpha L_0 \Delta T}$$

α coefficient of linear expansion

Linear expansion – holes ?



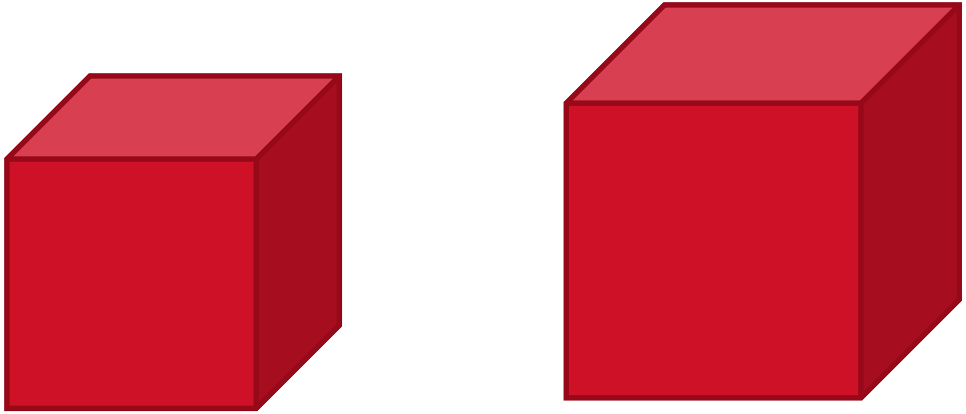
All lengths expand the same
Holes expand with the same ratio



Linear expansion in practice

Ex. 17.11,17.12 – Longest spanning Humber Bridge, UK (2220m) or tallest building Burj Khalifa, Dubai (828m), steel frames.

Volume expansion



V_0

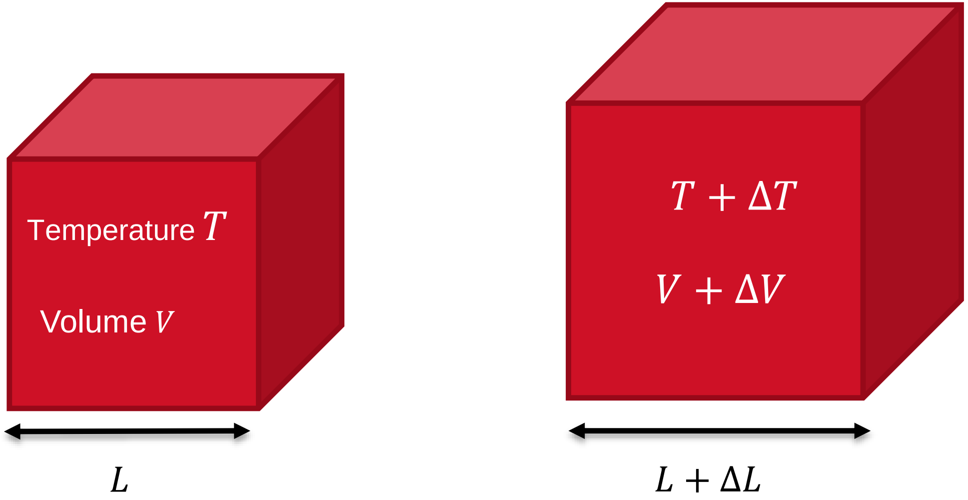
$V(T_0 + \Delta T) = V_0 + \Delta V$

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

β coefficient of volume expansion

$$\beta_{\text{liquids}} > \beta_{\text{solids}}$$

Linear expansion and Volume expansion



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

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

$$\frac{\Delta V}{\Delta L} \simeq \frac{\partial V}{\partial L}$$

$V_0 = L_0^3$ so $\dfrac{\partial V}{\partial L} = 3L_0^2$

and $\dfrac{\Delta V}{\Delta L} = \dfrac{\beta V_0}{\alpha L_0}$ so

$\beta V_0 = 3\alpha L_0^3$

$\Rightarrow \beta = 3\alpha$

Example of volume expansion

Table 17.2 Coefficients of Volume Expansion

Solids	β [K^{-1} or $(C°)^{-1}$]	Liquids	β [K^{-1} or $(C°)^{-1}$]
Aluminum	7.2×10^{-5}	Ethanol	75×10^{-5}
Brass	6.0×10^{-5}	Carbon disulfide	115×10^{-5}
Copper	5.1×10^{-5}	Glycerin	49×10^{-5}
Glass	$1.2–2.7 \times 10^{-5}$	Mercury	18×10^{-5}
Invar	0.27×10^{-5}		
Quartz (fused)	0.12×10^{-5}		
Steel	3.6×10^{-5}		

Ex. 17.14: Aluminium rivets in aircraft construction are made larger than the rivet holes, cooled with ”dry ice” (solid CO_2) before insertion.