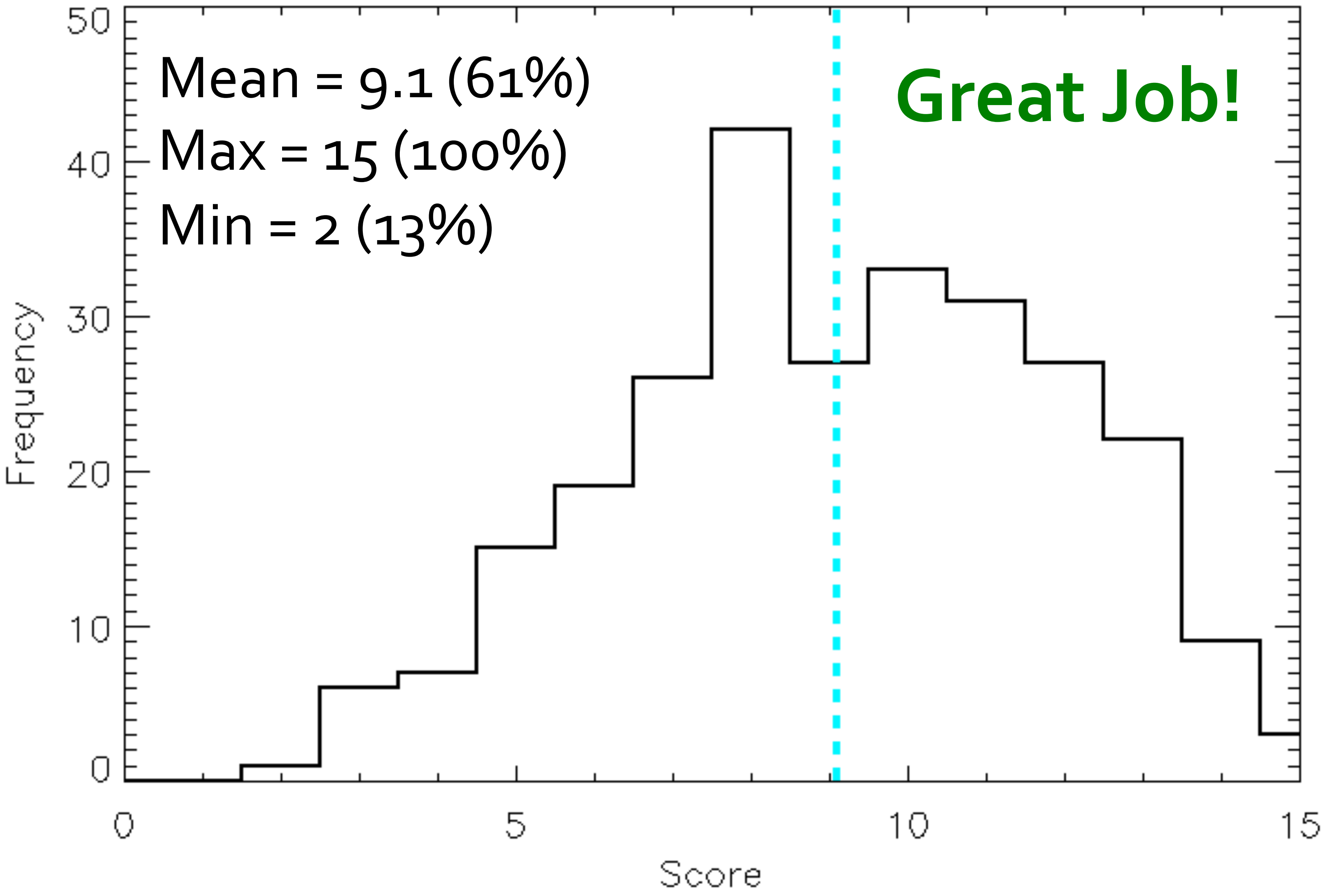
College Physics I: 1511
Mechanics & Thermodynamics

Professor Jasper Halekas
Van Allen Lecture Room 1
MWF 8:30-9:20 Lecture

Exam 2 Scores



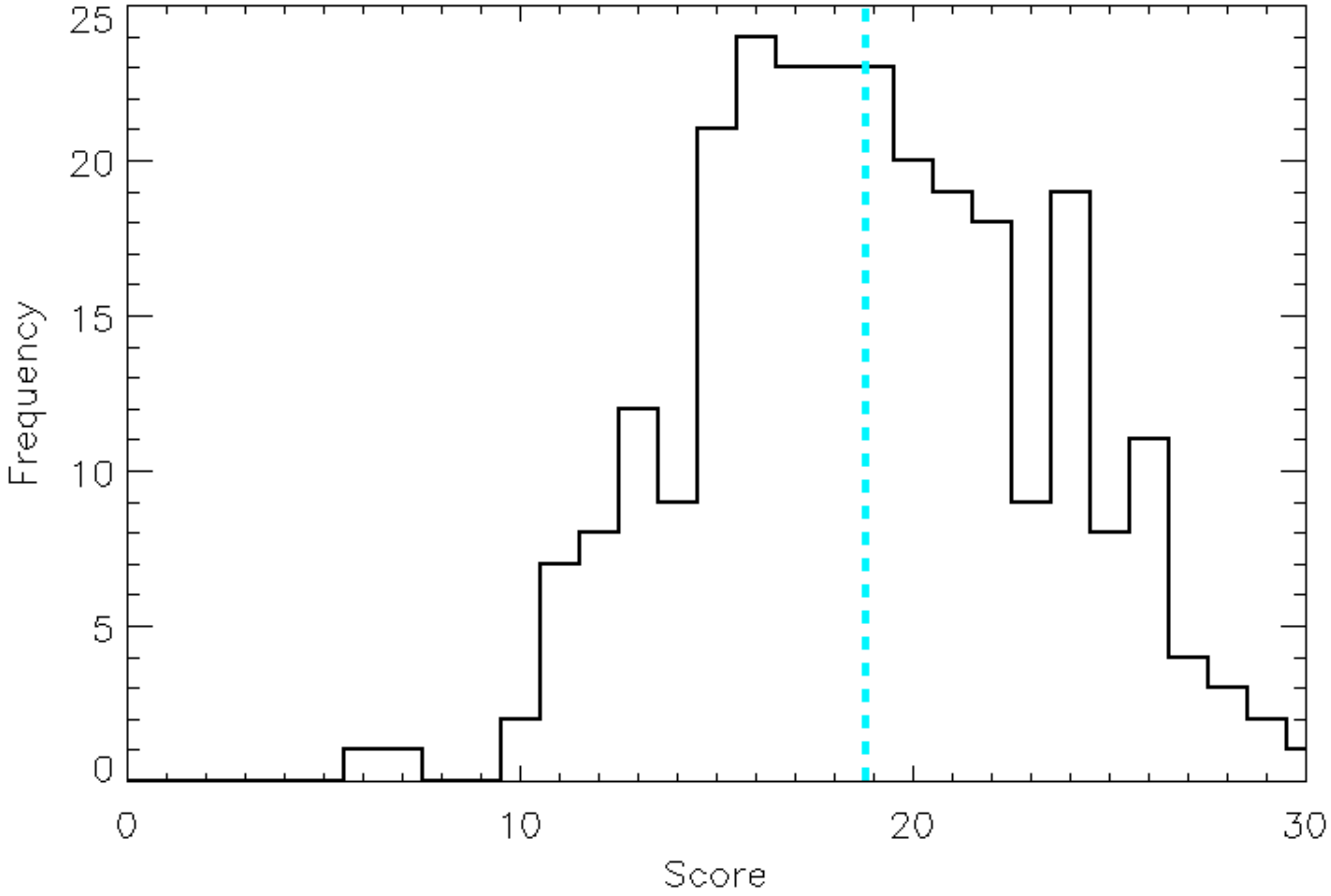
Mean = 9.1 (61%)

Max = 15 (100%)

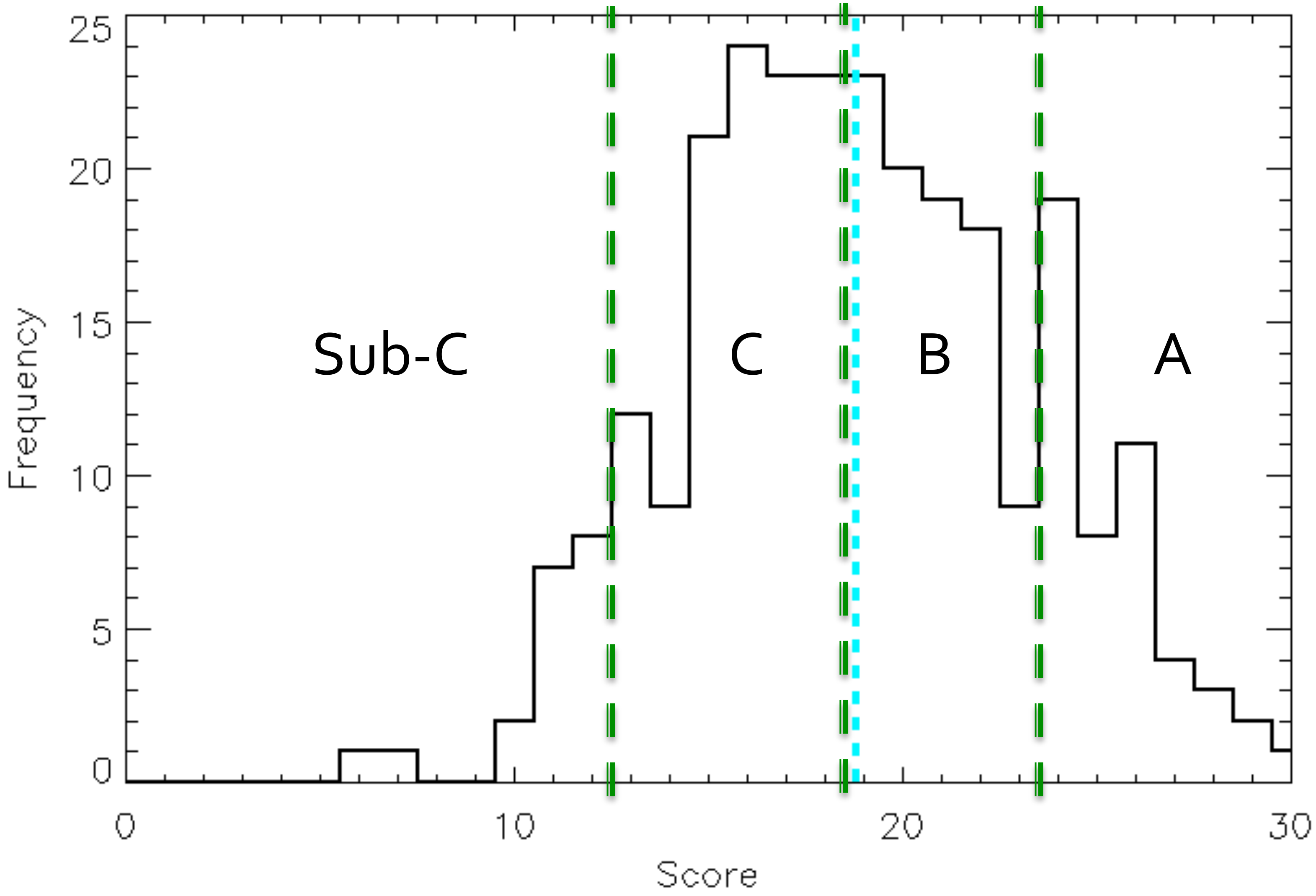
Min = 2 (13%)

Great Job!

Combined Exam Scores



Very Rough Grade Distribution (Based Only on Exam Scores)



Announcements I

- Students with valid excuses for missing the exam are taking makeups Tuesday (with a different test)
  - If anyone missed the exam and has not contacted me with a valid excuse, please be aware that Tuesday is the ***last*** possible date for you to take the exam
- I will post solutions to the exam after Tuesday
  - I will also be happy to discuss the exam after Tuesday
  - You can pick up your exam if you want after Tuesday

Announcements II

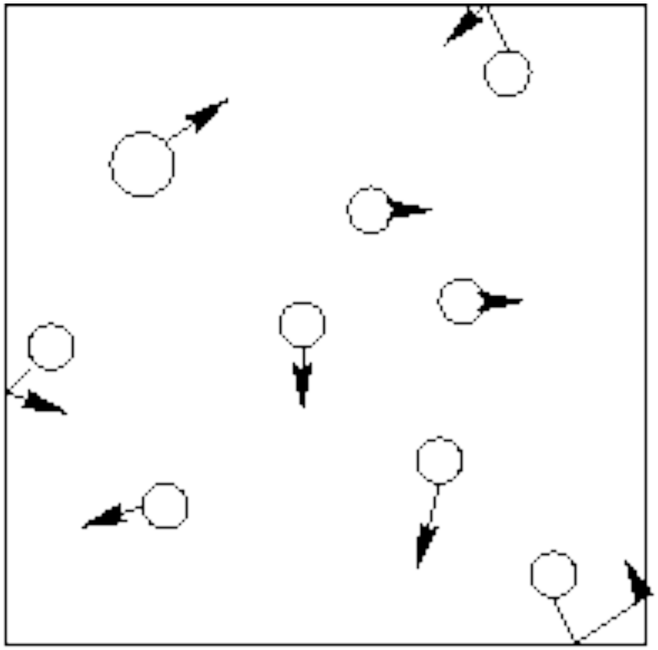
- Labs and homeworks as usual this week
  - Only three more labs!
  - Only four more homeworks!

Announcements III

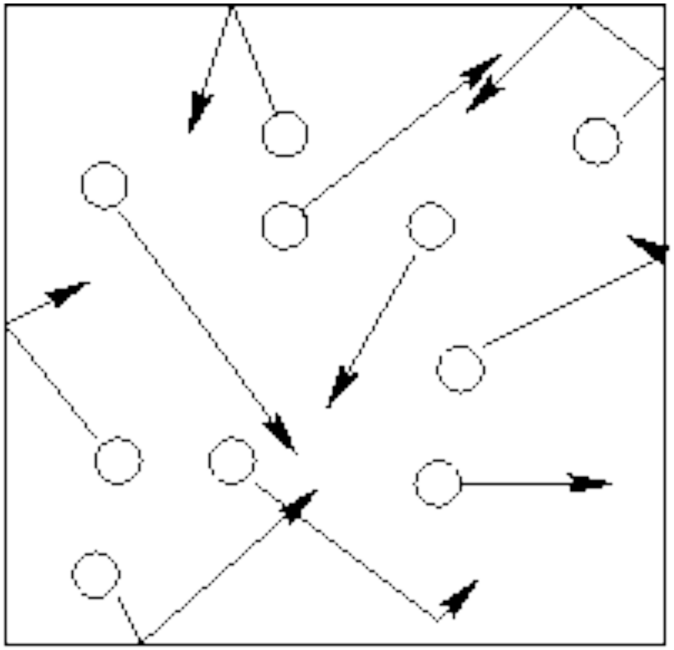
Definition: Temperature

- Common sense:
  - A measure of how “hot” or “cold” something is
- Scientific:
  - Temperature is a measurement of the average kinetic energy of the atoms or molecules in an object or system.

Temperature at the Microscopic Level

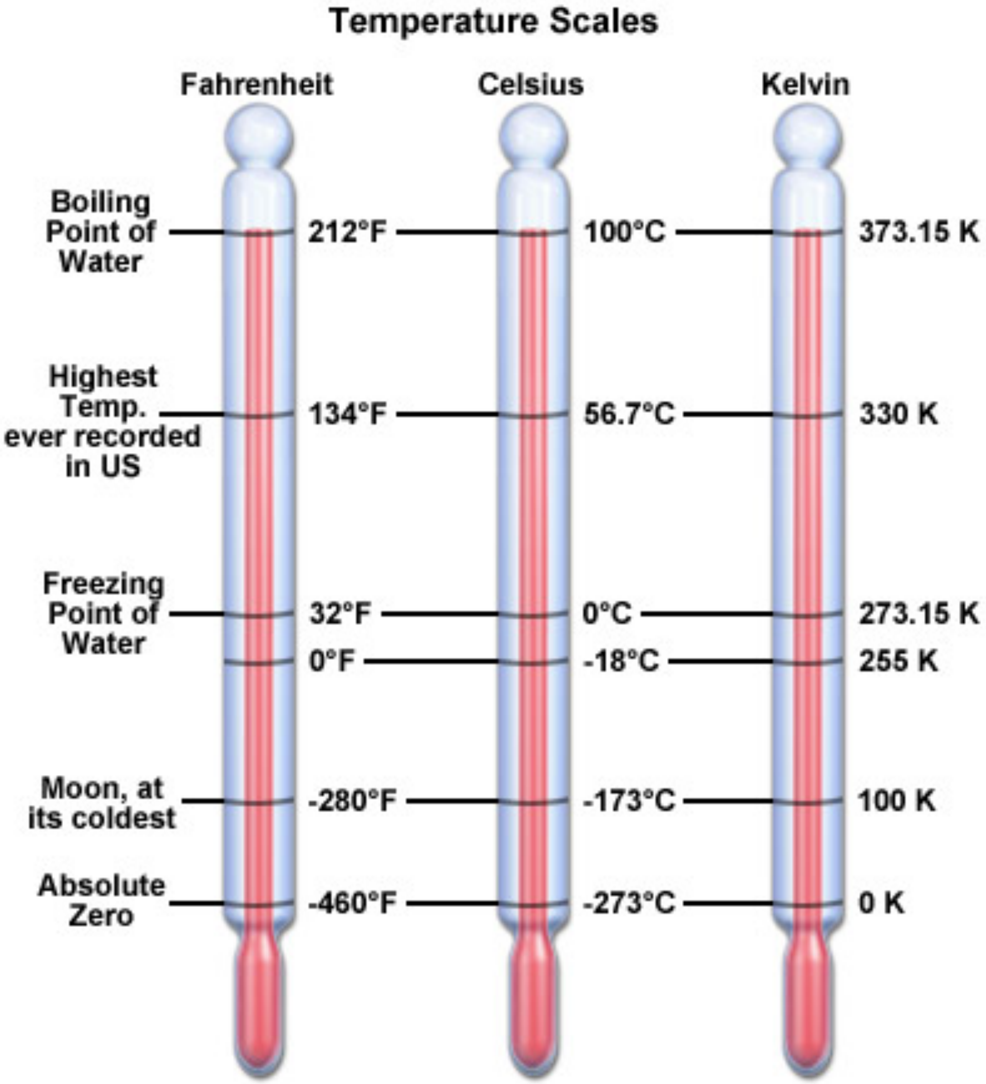


Cool gas, fewer and less energetic collisions

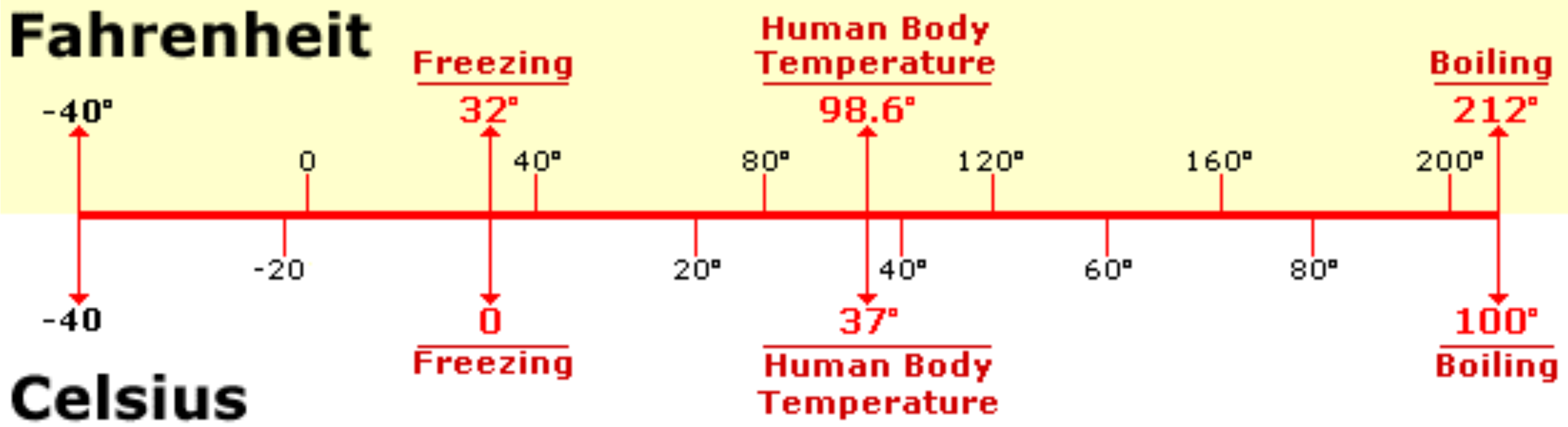


Hot gas, more and more energetic collision

Temperature Scales



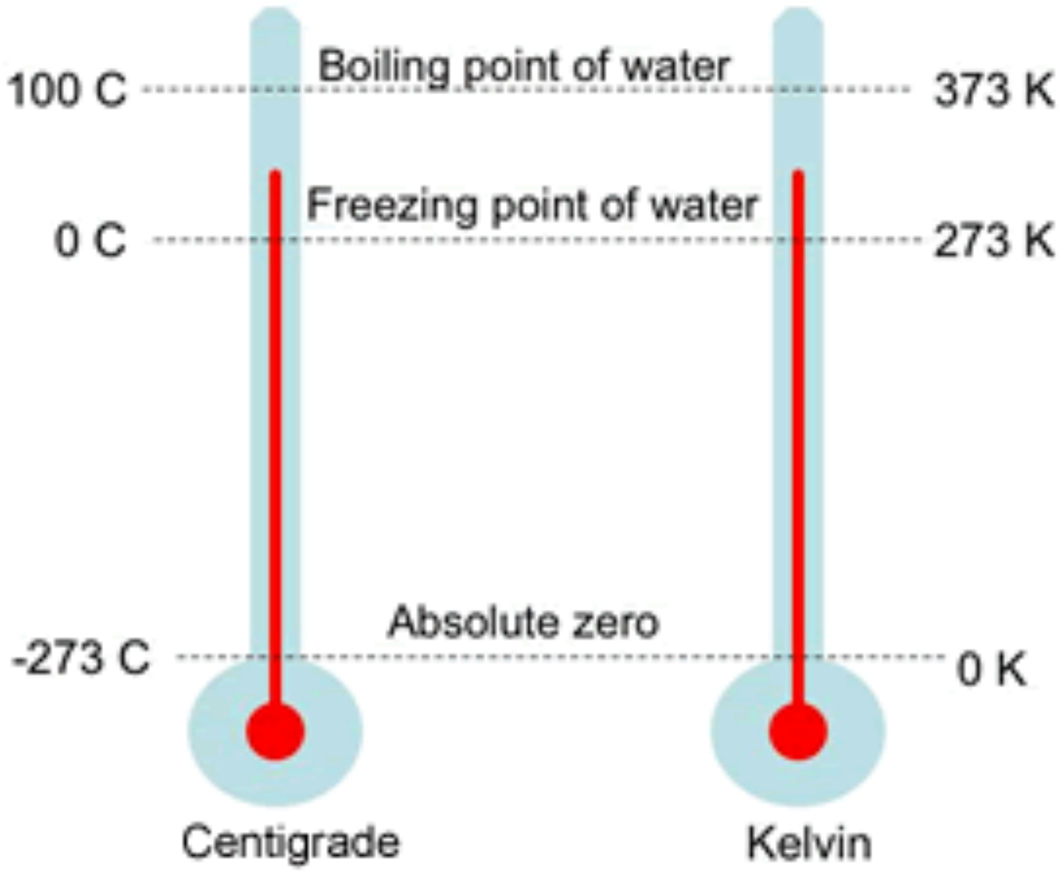
Celsius & Fahrenheit



$$^\circ C = (^\circ F - 32) \times 5 / 9$$

$$^\circ F = (^\circ C \times 9 / 5) + 32$$

Kelvin Temperature Scale



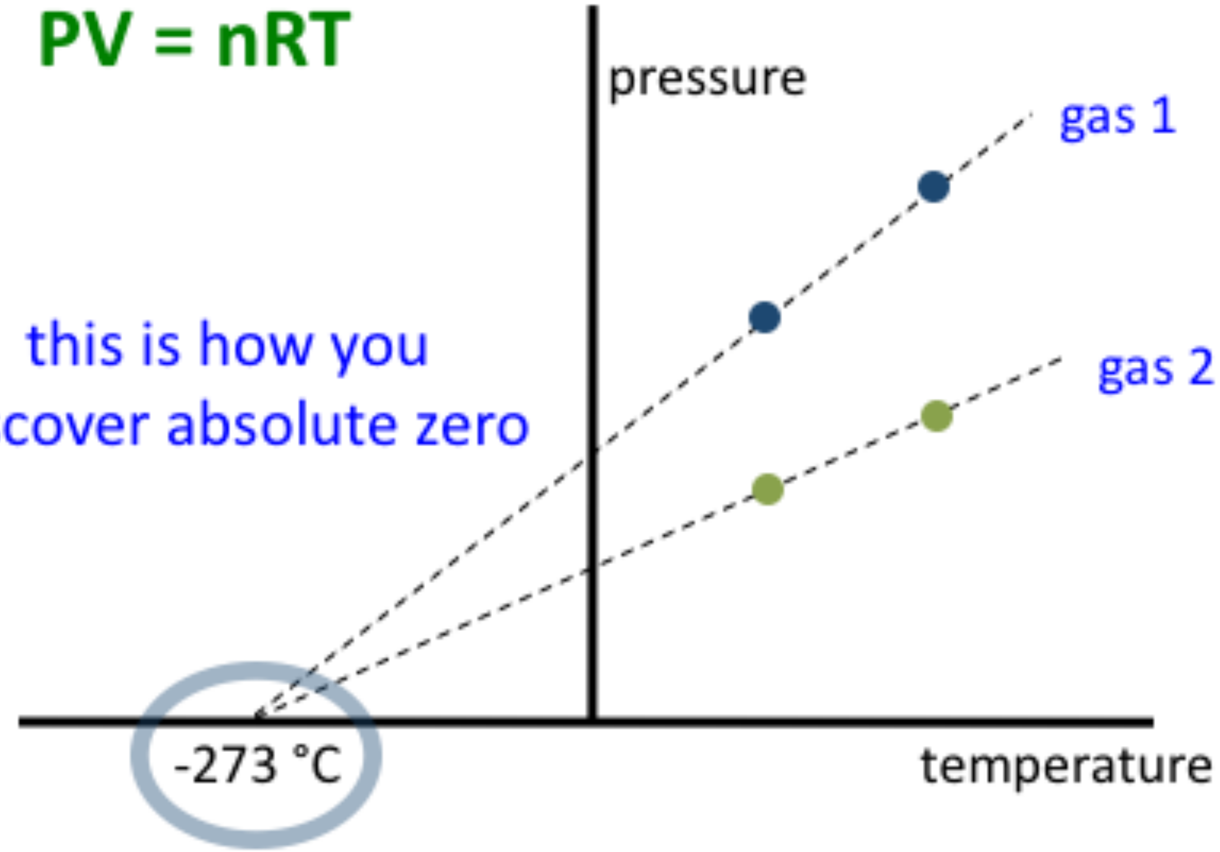
°C = K-273

Absolute Zero

Absolute Gas Temp. Scale

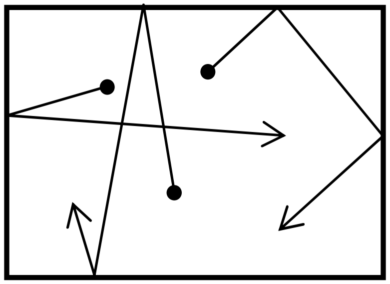
$PV = nRT$

this is how you
discover absolute zero

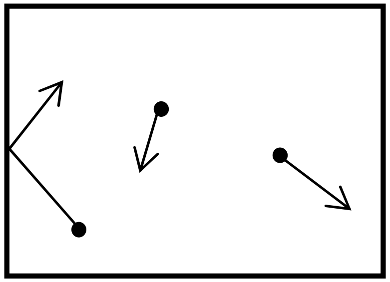


Absolute Zero

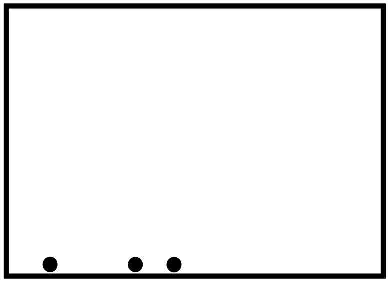
- Absolute zero means zero temperature
- Zero temperature (properly expressed in Kelvin) means zero kinetic energy for the molecules in a substance
- This means there is no motion – everything is "frozen solid"



gas at hi T

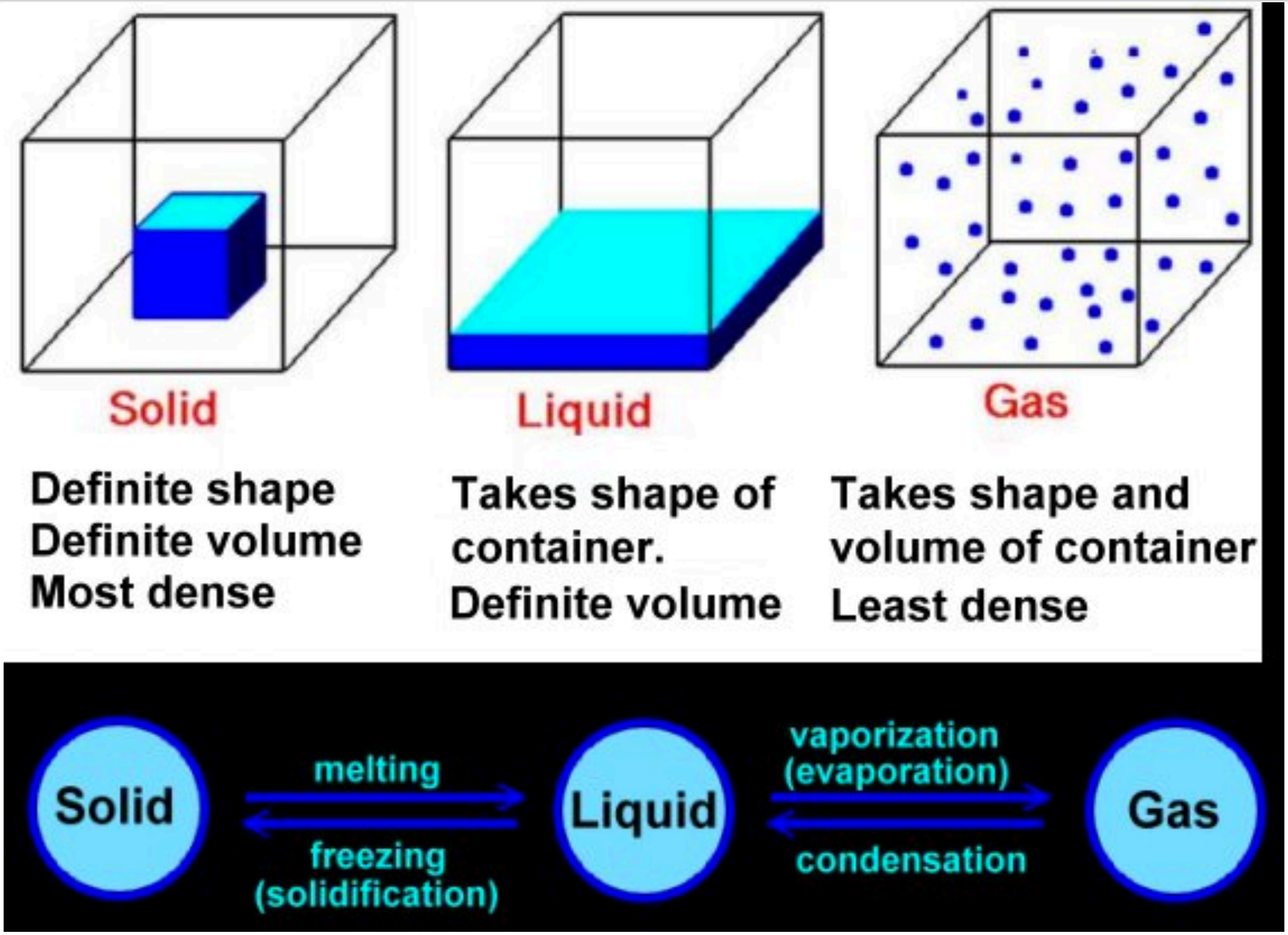


gas at lo T



gas at T = 0K

Phases of Matter



Solid
Definite shape
Definite volume
Most dense

Liquid
Takes shape of container.
Definite volume

Gas
Takes shape and volume of container
Least dense

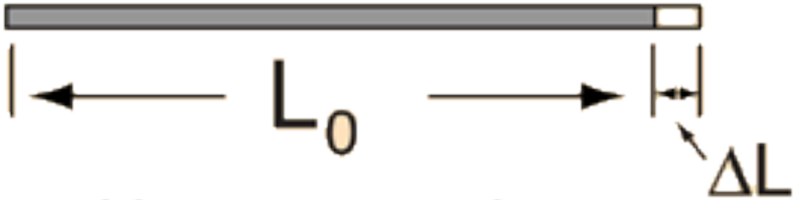
Everywhere this says "definite volume" it should say "almost definite volume"

Thermal Expansion/Contraction

- Almost all materials (solids, liquids, and gases) expand at least a little bit when heated, and contract when cooled

- Notable exceptions occur when materials change phases
  - e.g. When water cools and freezes to from a solid (ice), it actually expands

Linear Thermal Expansion



Linear expansion

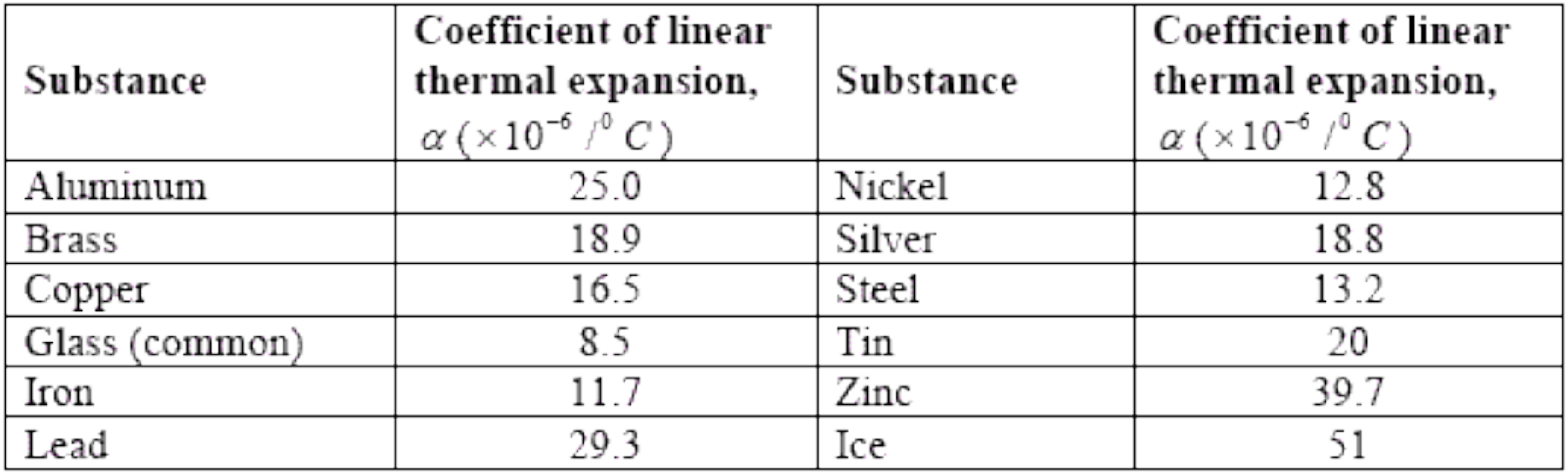
$$\frac{\Delta L}{L_0} = \alpha \Delta T$$

This is the fractional change in length, which is a natural quantity to use. Since one would expect a 4m rod to expand twice as much as a 2m rod, the fractional change would be the same.

Different substances expand by different amounts. An experimental expansion coefficient is necessary to quantify expansion.

The change in temperature determines the fractional change in length. One would expect that a 2°C change in temperature would lead to twice as much expansion as a 1°C change. This relationship shows that.

Thermal Expansion Coefficients



Substance	Coefficient of linear thermal expansion, $\alpha\ (\times 10^{-6}\ /^{0}C)$	Substance	Coefficient of linear thermal expansion, $\alpha\ (\times 10^{-6}\ /^{0}C)$
Aluminum	25.0	Nickel	12.8
Brass	18.9	Silver	18.8
Copper	16.5	Steel	13.2
Glass (common)	8.5	Tin	20
Iron	11.7	Zinc	39.7
Lead	29.3	Ice	51

Don’t use these values in homework problems – only use values given in book!

Concept Check

- Imagine you make a flat (at room temperature) two-sided strip with metals with different thermal expansion coefficients. What happens when you heat it?

A. Nothing
B. It bends towards the steel
C. It bends towards the copper

Concept Check

- Imagine you make a flat (at room temperature) two-sided strip with metals with different thermal expansion coefficients. What happens when you heat it?

A. Nothing
[✓ B. It bends towards the steel]
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Concept Check

- Imagine you make a flat (at room temperature) two-sided strip with metals with different thermal expansion coefficients. What happens when you *cool* it?

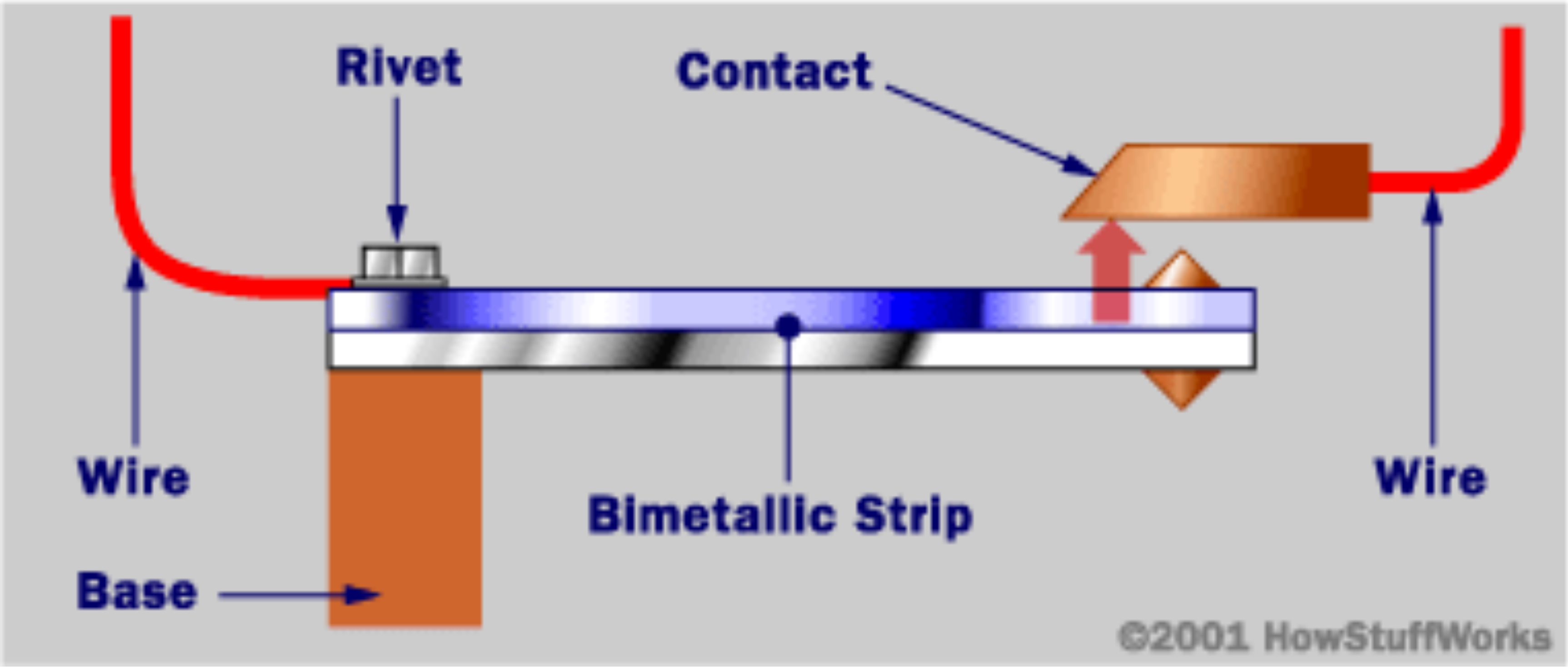
A. Nothing
B. It bends towards the steel
C. It bends towards the copper

Concept Check

- Imagine you make a flat (at room temperature) two-sided strip with metals with different thermal expansion coefficients. What happens when you *cool* it?

A. Nothing
B. It bends towards the steel
[✓ C. It bends towards the copper]

Bimetallic Switch



Concept Check

- A square metal plate with edge length L_o (area $A = L_o^2$) is heated so that it expands and its new edge length is 1.01 L_o. What is its new area?

- A: (1.01) L_o^2
- B: Less than (1.01) L_o^2
- C: More than (1.01) L_o^2

Concept Check

- A square metal plate with edge length L_o (area $A = L_o^2$) is heated so that it expands and its new edge length is $1.01\ L_o$. What is its new area?

- A: $(1.01)\ L_o^2$
- B: Less than $(1.01)\ L_o^2$
- C: More than $(1.01)\ L_o^2$

Answer: The new area is $(1.01\ L_o)^2 = 1.02\ L_o^2$.

$(1.01)^2 = (1+0.01)(1.01) = 1.01 + (0.01)(1.01) \cong$

$1.01 + 0.01 = 1.02$

Binomial Expansion and Thermal Expansion

- $(1+x)^2 = 1 + 2x + x^2 \sim 1+2x$ (for $x \ll 1$)

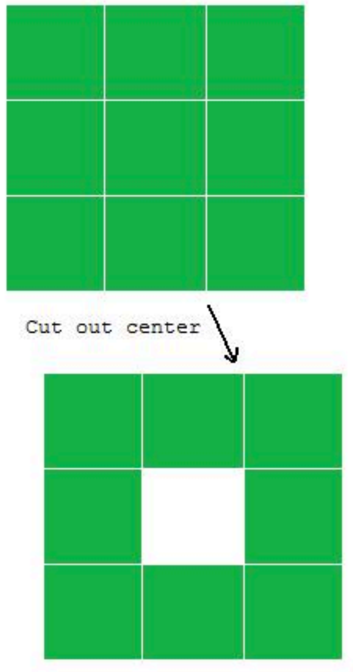
- Therefore area expansion has a coefficient twice that of linear expansion

- Similarly:
  - $(1+x)^3 \sim 1 + 3x$ (For $x \ll 1$)
  - Therefore volume expansion has a coefficient three times that of linear expansion

Concept Check

- Imagine you take a square sheet of metal, cut out the center, and then heat. What happens to the size of the hole?

A. Stays the same
B. Gets bigger
C. Gets smaller



Concept Check

- Imagine you take a square sheet of metal, cut out the center, and then heat. What happens to the size of the hole?

A. Stays the same
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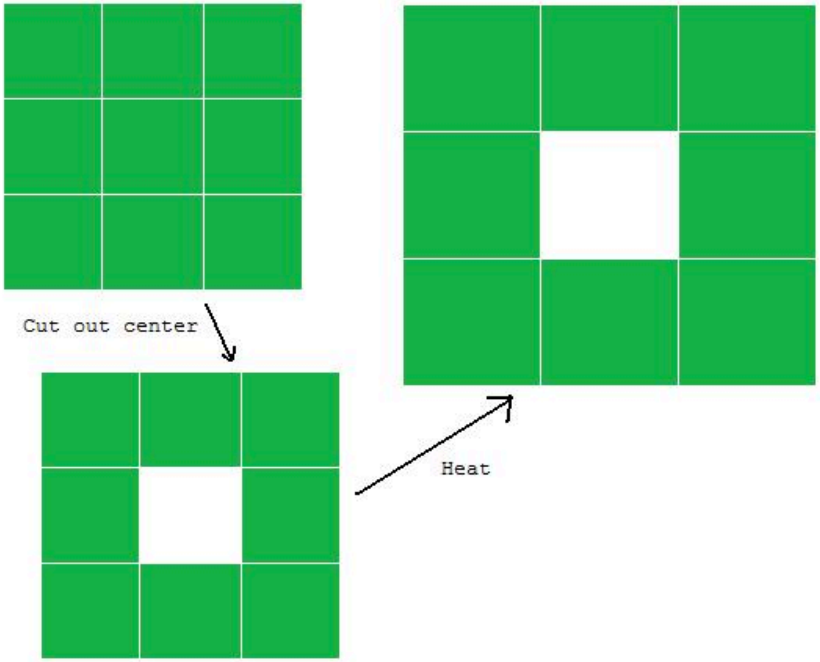
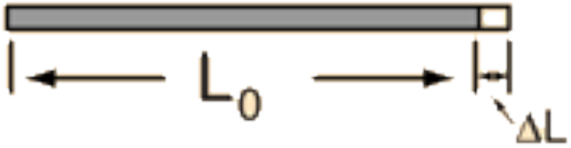
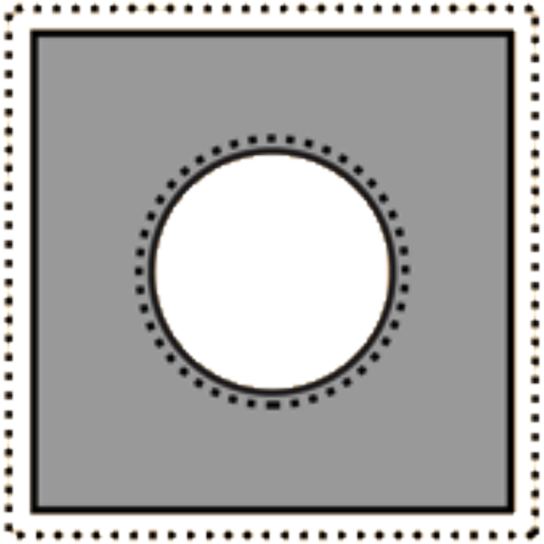


Thermal Expansion



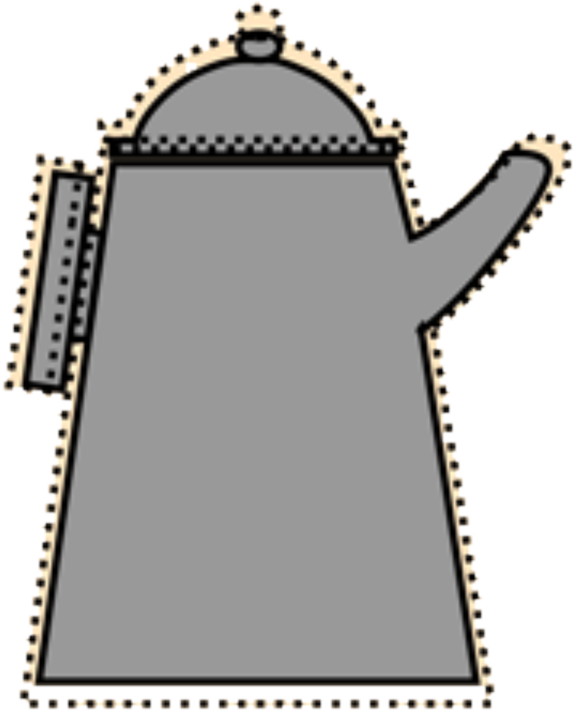
Linear expansion

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



Area expansion

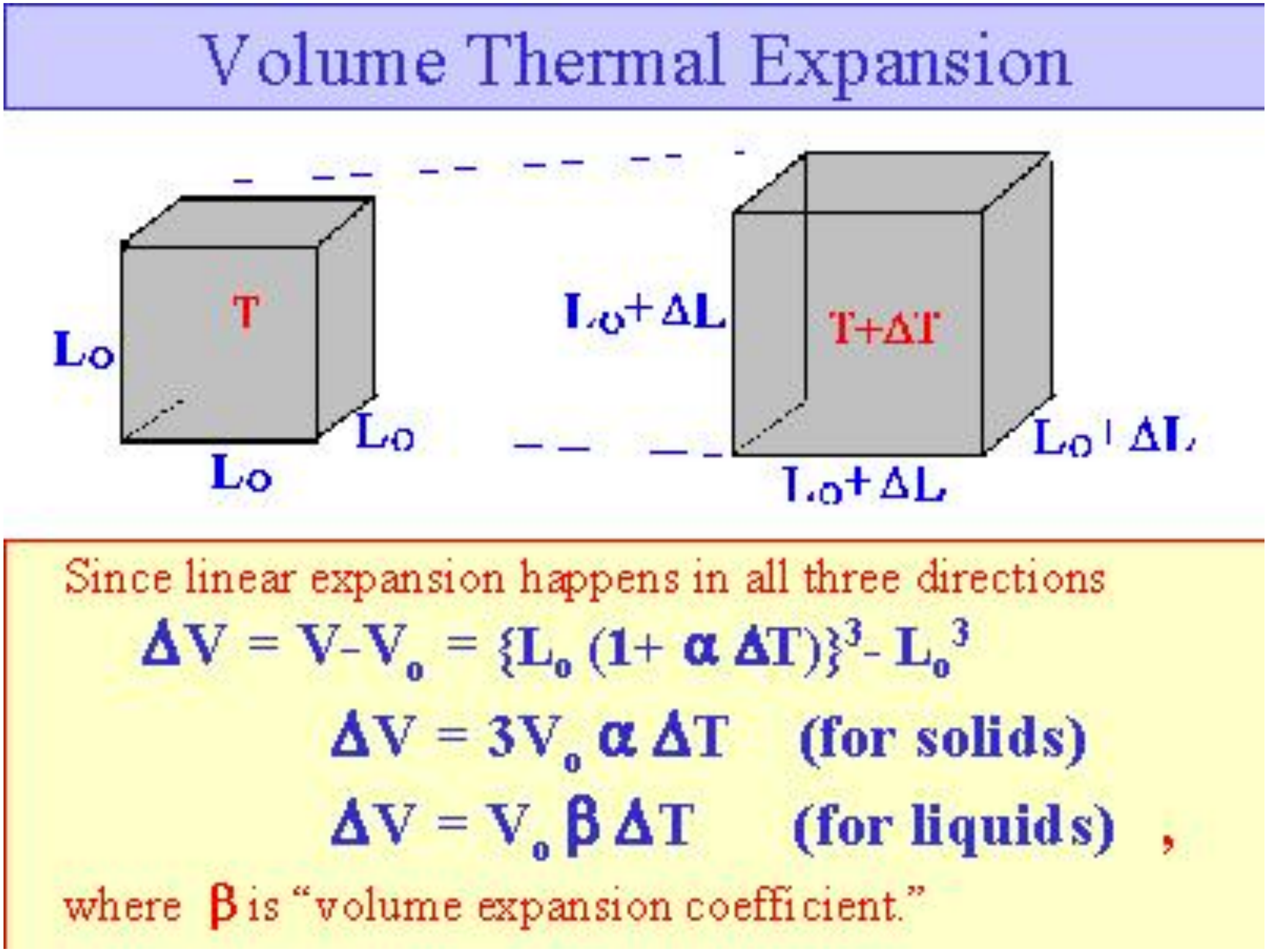
$$\frac{\Delta A}{A_0} = 2\alpha \Delta T$$



Volume expansion

$$\frac{\Delta V}{V_0} = 3\alpha \Delta T$$

Volume Thermal Expansion



Volume Thermal Expansion

Since linear expansion happens in all three directions

$$\Delta V = V - V_0 = \{L_0\,(1 + \alpha\,\Delta T)\}^3 - L_0^3$$

$$\Delta V = 3V_0\,\alpha\,\Delta T \qquad \text{(for solids)}$$

$$\Delta V = V_0\,\beta\,\Delta T \qquad \text{(for liquids)} \quad ,$$

where β is "volume expansion coefficient."

Thermal Expansion Coefficients

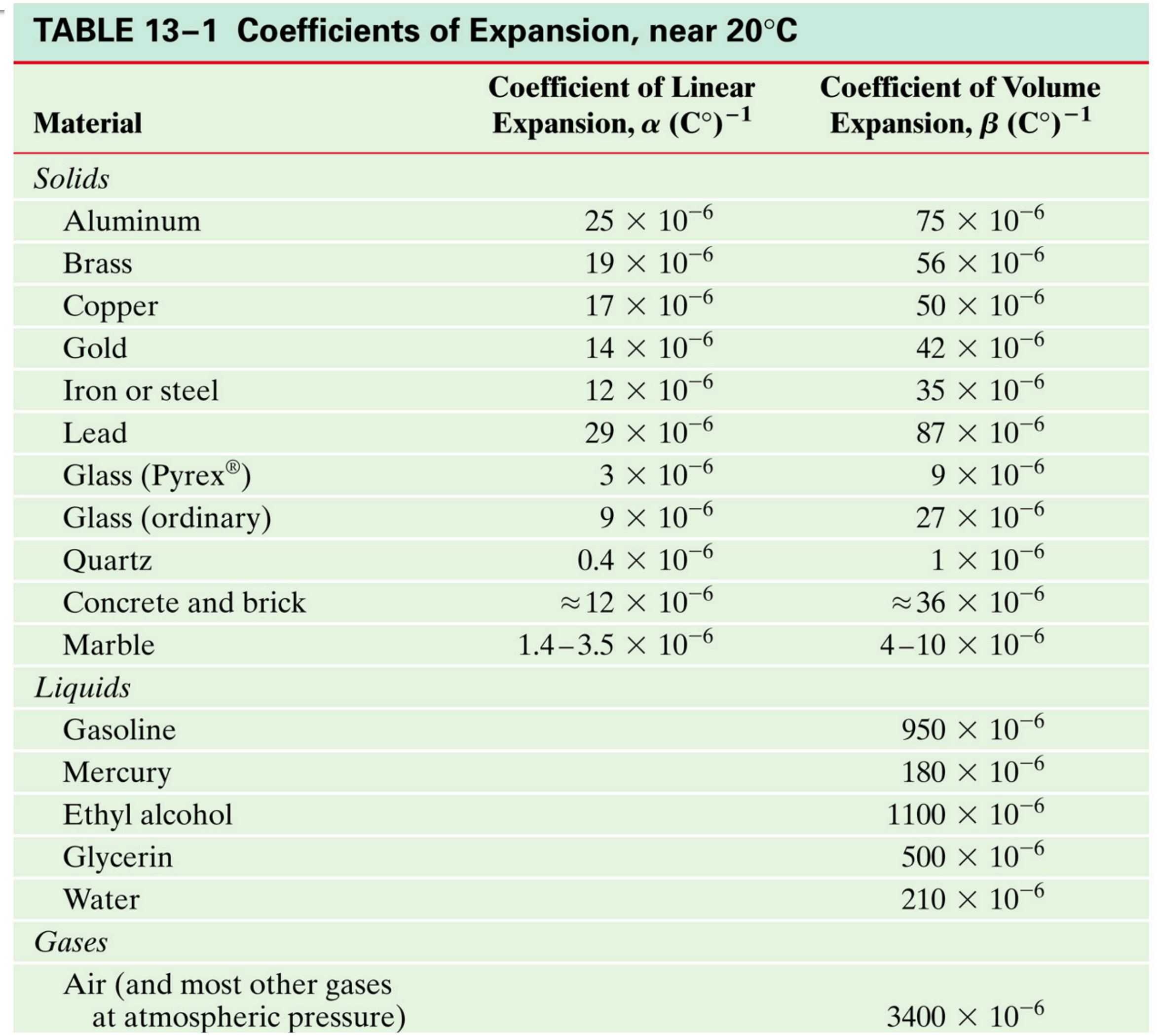


TABLE 13–1 Coefficients of Expansion, near 20°C

Material	**Coefficient of Linear Expansion, α $(\mathrm{C}^\circ)^{-1}$**	**Coefficient of Volume Expansion, β $(\mathrm{C}^\circ)^{-1}$**
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Copper	17×10^{-6}	50×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	35×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Glass (Pyrex®)	3×10^{-6}	9×10^{-6}
Glass (ordinary)	9×10^{-6}	27×10^{-6}
Quartz	0.4×10^{-6}	1×10^{-6}
Concrete and brick	$\approx 12 \times 10^{-6}$	$\approx 36 \times 10^{-6}$
Marble	$1.4\text{–}3.5 \times 10^{-6}$	$4\text{–}10 \times 10^{-6}$
Liquids		
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Ethyl alcohol		1100×10^{-6}
Glycerin		500×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases at atmospheric pressure)		3400×10^{-6}

Don’t use these values in homework problems – only use values given in book!