THERMAL EXPANSION AND PHASE TRANSITION




Thermal Expansion

- is the tendency of matter to change in volume in response to a change in temperature
- in expansion, there is a change in the average separation between the atoms in the object
- every linear dimension increases by the same percentage with an increase in temperature

Average Coefficient of Linear Expansion

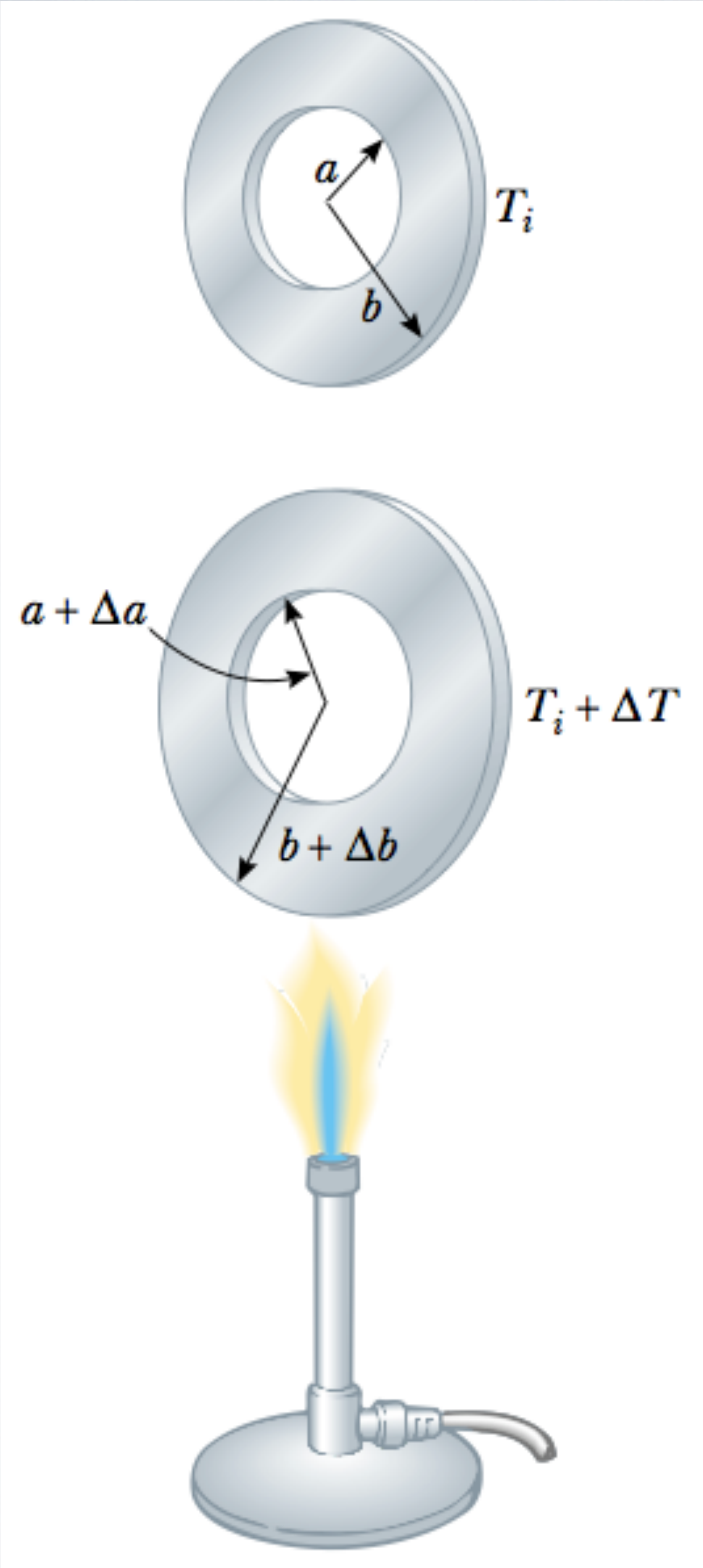
$$\alpha = \frac{\Delta L / L_i}{\Delta T}$$

$L_i \Rightarrow$ initial length

$L_f \Rightarrow$ final length

$\Delta L \Rightarrow L_f - L_i$

$\alpha \Rightarrow$ coefficient of linear expansion



Thermal expansion of a homogeneous metal washer. As the washer is heated, all dimensions increase. (The expansion is exaggerated in this figure.)

Average Coefficient of Volume Expansion

$$\beta = \frac{\Delta V / V_i}{\Delta T}$$

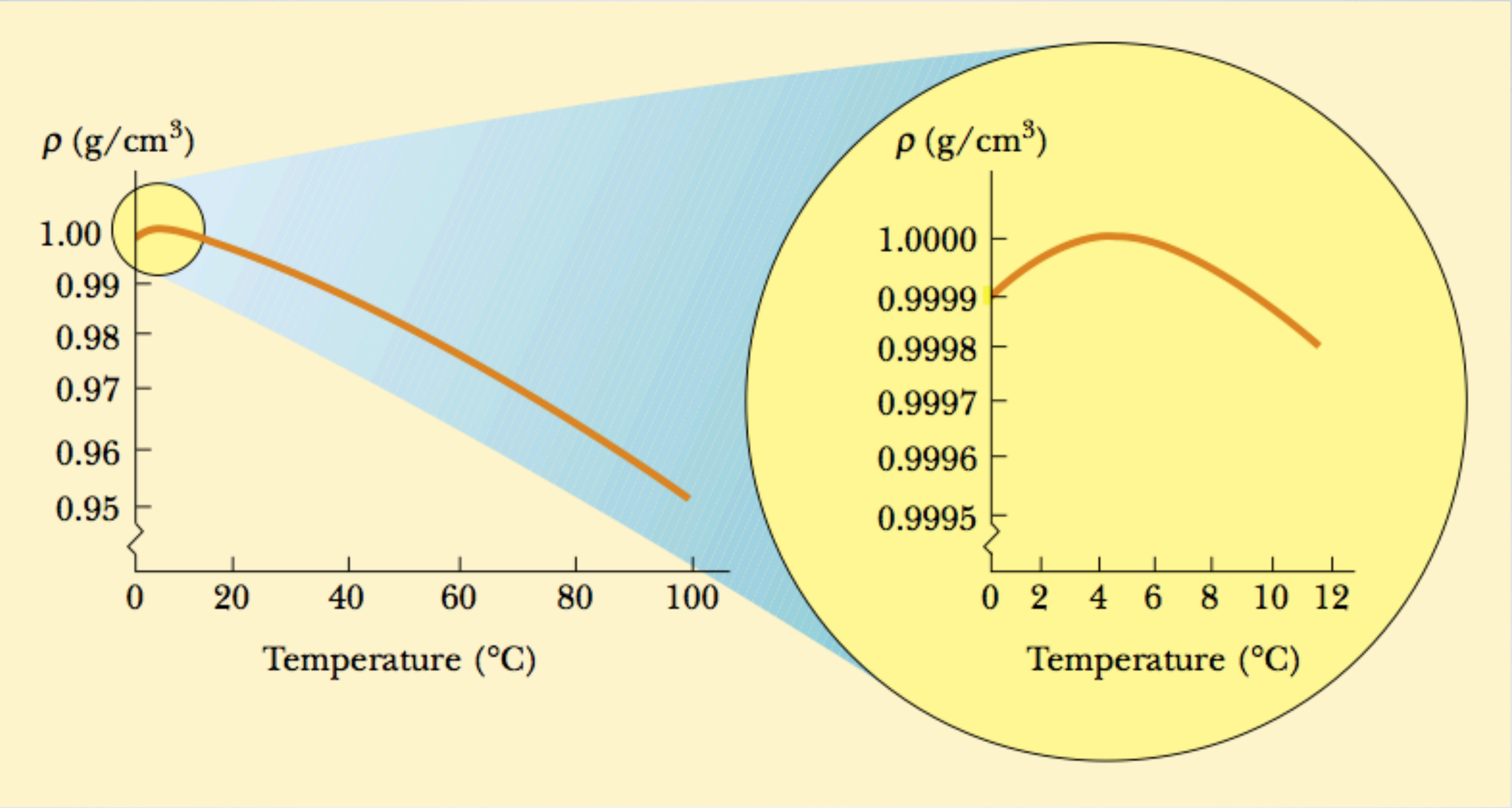
$V_i \Rightarrow$ initial volume

$V_f \Rightarrow$ final volume

$\Delta V \Rightarrow V_f - V_i$

$\beta \Rightarrow$ coefficient of volume expansion

How about water? How does it behave?



How the density of water at atmospheric pressure changes with temperature.

TABLE 19.2 Average Expansion Coefficients for Some Materials Near Room Temperature

Material	Average Linear Expansion Coefficient (α) $(°C)^{-1}$	Material	Average Volume Expansion Coefficient (β) $(°C)^{-1}$
Aluminum	24×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline	9.6×10^{-4}
Invar (Ni–Fe alloy)	0.9×10^{-6}	Air at 0°C	3.67×10^{-3}
Concrete	12×10^{-6}	Helium	3.665×10^{-3}

Exercises

- A steel girder is 200 m long at 20°C. If the extremes of temperature to which it might be exposed are –30 °C to +40 °C, how much will it contract and expand?
- Rubber has a negative average coefficient of linear expansion. What happens to the size of a piece of rubber as it is warmed?

Exercises

- A certain glass rod is 30.0 cm long by 1.50 cm in diameter. If the temperature of the rod increases by 65°C, what is the increase in (*a*) its length, (*b*) its diameter, and (*c*) its volume? (Assume that $\alpha = 9.00 \times 10^{-6}/°C$)

- It is shown that $3\alpha = \beta$, now show that the change in area of a rectangular plate is given by

$$\Delta A = 2\alpha A_i \Delta T$$

Latent Heat (*L*)

- is the amount of energy released or absorbed by a chemical substance during a change of state or a phase transition

$$L \equiv \frac{Q}{m}$$

L ⇒ latent heat

Q ⇒ heat

m ⇒ *mass*

During phase change, the amount of energy transferred depends on the amount of substance involved

Heat transfer in a phase change

- heat entering the substance — (**+**)
- heat leaving the substance — (**–**)

$$Q = \pm mL$$

- note: both L_v and the boiling temperature of a material depend on pressure

The **boiling point** of water changes with altitude.

- As you go higher, the boiling temperature *decreases*.
- At sea level, the boiling point of water is 212 °F (100 °C).
- As a general rule, the boiling point temperature *decreases* by **1 F° for every 540 feet of altitude** (0.56 C° for every 165 meters)
- there is *less* atmospheric pressure on the surface of liquids

TABLE 20.2 Latent Heats of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Helium	−269.65	5.23×10^3	−268.93	2.09×10^4
Nitrogen	−209.97	2.55×10^4	−195.81	2.01×10^5
Oxygen	−218.79	1.38×10^4	−182.97	2.13×10^5
Ethyl alcohol	−114	1.04×10^5	78	8.54×10^5
Water	0.00	3.33×10^5	100.00	2.26×10^6
Sulfur	119	3.81×10^4	444.60	3.26×10^5
Lead	327.3	2.45×10^4	1 750	8.70×10^5
Aluminum	660	3.97×10^5	2 450	1.14×10^7
Silver	960.80	8.82×10^4	2 193	2.33×10^6
Gold	1 063.00	6.44×10^4	2 660	1.58×10^6
Copper	1 083	1.34×10^5	1 187	5.06×10^6

- latent heat of solidification = latent heat of fusion
- latent heat of vaporization = latent heat of condensation

Specific Heat (*c*)

- is the heat capacity per unit mass of a substance

Heat Capacity (*C*)

- is the amount of energy needed to raise the temperature of a particular sample of substance by 1 °C

$$Q = mc\Delta T \qquad Q = C\Delta T$$

c ⇒ heat capacity

Q ⇒ heat

m ⇒ *mass*

ΔT ⇒ temperature change

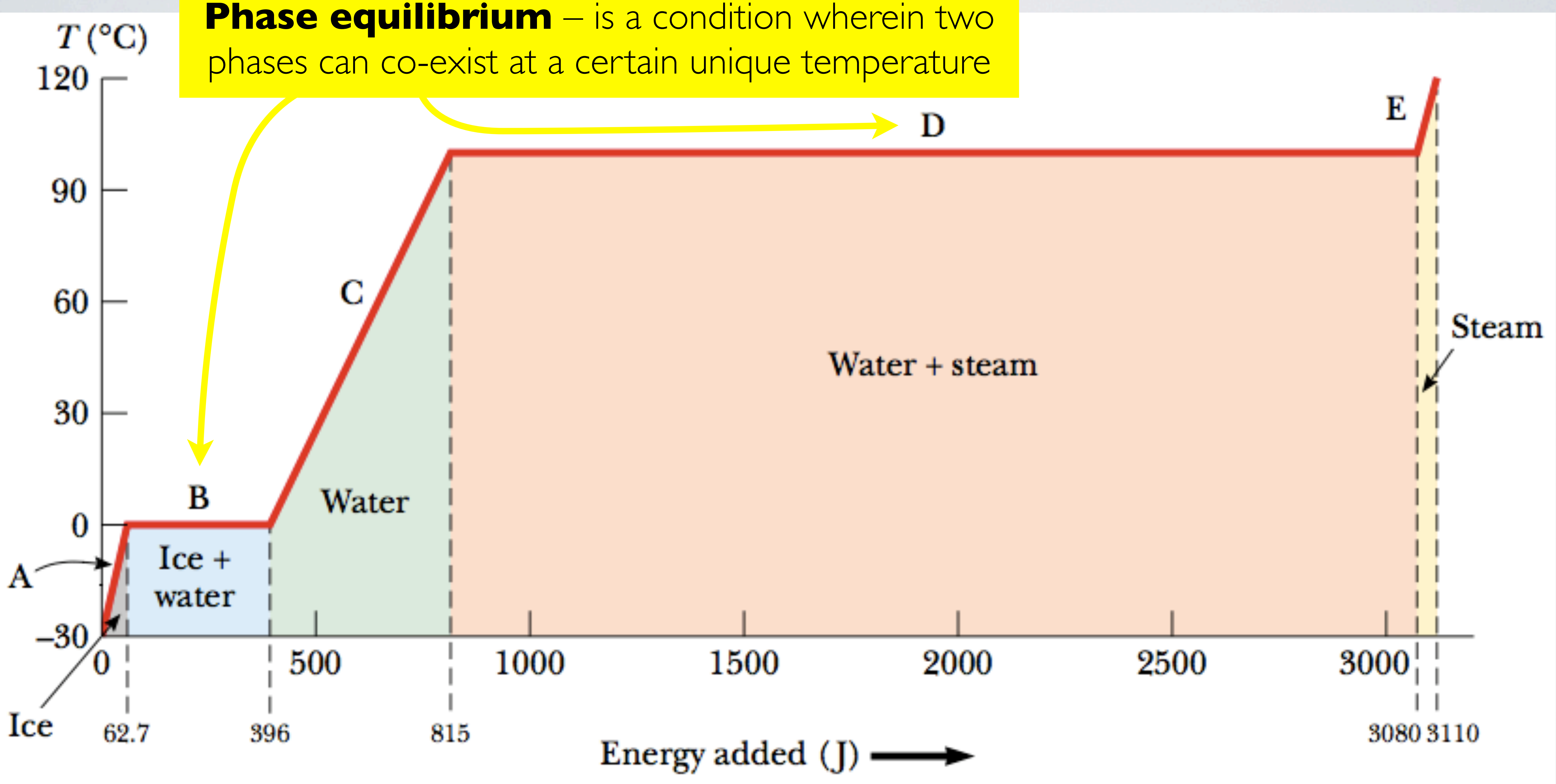
TABLE 20.1 Specific Heats of Some Substances at 25°C and Atmospheric Pressure

Substance	Specific Heat c J/kg·°C	Specific Heat c cal/g·°C
Elemental Solids		
Aluminum	900	0.215
Beryllium	1 830	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Gold	129	0.030 8
Iron	448	0.107
Lead	128	0.030 5
Silicon	703	0.168
Silver	234	0.056
Other Solids		
Brass	380	0.092
Glass	837	0.200
Ice (−5°C)	2 090	0.50
Marble	860	0.21
Wood	1 700	0.41
Liquids		
Alcohol (ethyl)	2 400	0.58
Mercury	140	0.033
Water (15°C)	4 186	1.00
Gas		
Steam (100°C)	2 010	0.48

Phase Transition of Water

- transfer of energy (heat) doesn't result in a change in temperature

Phase equilibrium – is a condition wherein two phases can co-exist at a certain unique temperature



A plot of temperature versus energy added when 1.00 g of ice initially at –30.0°C is converted to steam at 120.0°C.

Chapter problem 20-66
Serway (5th ed), p. 638

A cooking vessel on a slow burner contains 10.0 kg of water and an unknown mass of ice in equilibrium at 0°C at time $t = 0$. The temperature of the mixture is measured at various times, and the result is plotted in the figure. During the first 50.0 min, the mixture remains at 0°C. From 50.0 min to 60.0 min, the temperature increases to 2.00°C. Neglecting the heat capacity of the vessel, determine the initial mass of the ice.