Thermodynamics

↳ relationship of heat and temperature to energy and work

Temperature and heat are not the same thing.

Temperature? → What does it do?

- generally it causes them to expand
- in a closed volume of gas, it increases the pressure
- changes electrical resistance of conducting wire

Temperature is defined by zeroth law of Thermodynamics

Conversion between T scales

Water	Freeze	Boil	Diff.
	0 °C	100 °C	100 °C
	32 °F	212 °F	180 °F

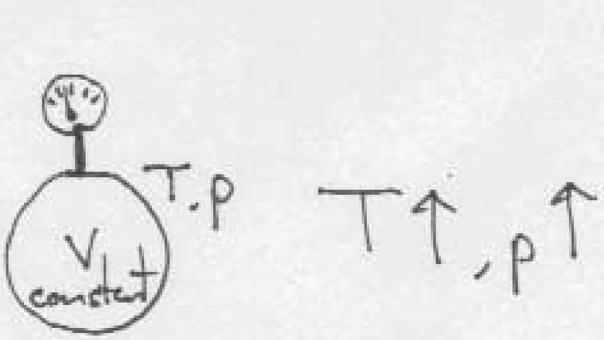
$$T_F(T_c) = \frac{180\,°F}{100\,°c}(T_c) + \text{const.}$$

$$T_F(0) = \frac{9}{5}(0) + \text{const} = 32$$

$$\text{const} = 32$$

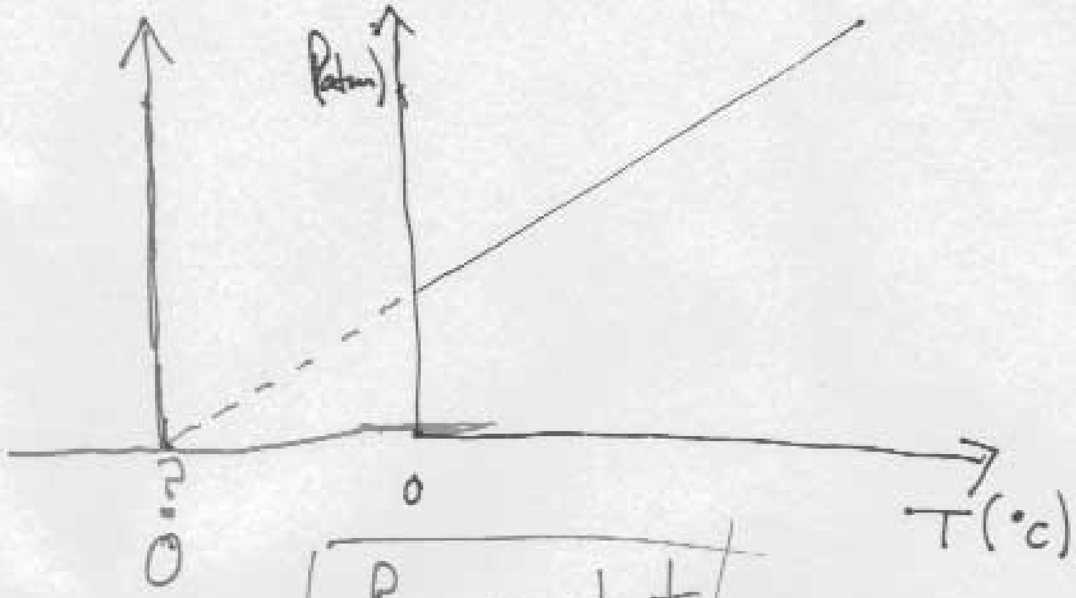
$$\boxed{T_F = \frac{9}{5}T_c + 32\,°c}$$

M.3 Ideally, our T scale will not depend on the properties of a particular material.



Many gases (ideal)

$$\frac{\Delta p}{\Delta T} = \text{constant}$$



$$\boxed{\frac{p}{T} \text{ constant}}$$

Meaning that $\frac{p_1}{T_1} = \frac{p_2}{T_2}$

or

$\frac{p_1}{p_2} = \frac{T_1}{T_2}$ 1. constant V
2. T in K

Kelvin T scale.

Example

A constant volume gas thermometer is calibrated in dry ice (CO_2 in solid state, -80.0°C) and in boiling ethyl alcohol (78.0°C). The pressure readings are 0.900 atm and 1.635 atm. What is the temperature value in °C when extrapolating back to $p=0$?

LINEAR: $p = A + BT$ A, B are constants

① $0.900 \text{ atm} = A + (-80.0°C)B$

② $1.635 \text{ atm} = A + (78.0°C)B$

$A = 0.900 \text{ atm} + (80.0°C)B$

↳ ②

$B = 4.65 \times 10^{-3} \frac{\text{atm}}{°C}$

$A = 1.27 \text{ atm}$

$p = 1.27 \text{ atm} + (4.65 \times 10^{-3} \text{ atm}/°C)T$

$p = 0 = 1.27 \text{ atm} + (4.65 \times 10^{-3} \text{ atm}/°C)T$

solve for T

$T = -274°C$

Absolute zero: 0 K, -273.15 °C

because all we did was shift our scale

$$\boxed{T_K = T_C + 273.15\,^\circ C}$$

17.4 Thermal Expansion

Example

The active element of a laser is made of a glass rod 30.0 cm long by 1.50 cm in diameter. If the temperature of the rod increases by 65.0°C, what is the increase in

a) its length?

b) its diameter?

a) $\Delta L = \alpha L_0 \Delta T$

$= (9.00 \times 10^{-6}\ {}^\circ C^{-1})(0.300\ m)(65.0^\circ C)$

$= 1.76 \times 10^{-4}\ m$

b) Diameter is a linear dimension, so same equation applies

$\Delta D = \alpha D_0 \Delta T$

$= (9.00 \times 10^{-6}\ {}^\circ C^{-1})(0.0150\ m)(65.0^\circ C)$

$= 8.78 \times 10^{-6}\ m$

What about volume?

β - coefficient of volume expansion

$$\Delta V = \beta V_0 \Delta T$$

Can we relate α to β?

$V_0 = L^3$

change in volume $dV = \frac{dV}{dL}\, dL = 3L^2\, dL$

$$dL = \alpha L_0\, dT$$

$$V_0 = L_0^3$$

$$dV = 3L_0^2\, \alpha L_0\, dT$$

$$= \underset{\beta}{\underset{\shortparallel}{\boxed{3\alpha}}}\, V_0\, dT$$

Increase in volume for glass rod?

$$V_0 = \pi r^2 L = \frac{\pi}{4}(0.0150\,m)^2(0.300\,m)$$

$$= 5.30 \times 10^{-5}\, m^3$$

$$\Delta V = \beta V_0 \Delta T = 3\alpha V_0 \Delta T$$

$$= 93.0 \times 10^{-9}\, m^3$$

3-8

A hollow aluminum ($\beta = 7.2 \times 10^{-5}\,°C^{-1}$) cylinder 20.0 cm deep has an internal capacity of 2.000 L at 20.0°C. It's completely with turpentine, and then slowly warm to 80.0°C.

a) How much turpentine overflows?

b) If the cylinder is then cooled back to 20.0°C, how far below the cylinder's rim does the surface of the turpentine recede?

---

a) $\Delta V = \beta V_0 \Delta T$

The overflow

$$V_{OVER} = \Delta V_T - \Delta V_{Al}$$

$$= (\beta_T V_0 \Delta T) - (\beta_{Al} V_0 \Delta T)$$

$$= V_0 \Delta T (\beta_T - \beta_{Al})$$

$$= (2.000\,L)(60.0\,°C)(9.00 \times 10^{-4}\,°C^{-1} - 0.72 \times 10^{-4}\,°C^{-1})$$

$$= 0.0994\,L$$

b) After warming the whole volume of turpentine is

$$V' = V_0 + \beta_T V_0 \Delta T$$

$$= 2.000\,L + (9.00 \times 10^{-4}\,{}^\circ C^{-1})(2.000\,L)(60.0^\circ C)$$

$$= 2.108\,L$$

fraction lost is

$$\frac{0.0994\,L}{2.108\,L} = 4.7 \times 10^{-2}$$

or 4.7%

$$\Delta h = (4.71 \times 10^{-2})(20.0\,cm)$$

$$= 0.943\,cm$$

Thermal Stress

$$\boxed{\frac{F}{A} = -Y \alpha \Delta T}$$

F - tension

A - x sectional area

Y - Young's Modulus - ratio of stress to strain in a material

α - coef. of linear expansion

ΔT - T change

3-10

$\Delta T \downarrow$, ΔT is negative, F and $\frac{F}{A}$ are ~~negative~~ positive

↳ a tensile force is needed to maintain the length of the material

$\Delta T \uparrow$, F and $\frac{F}{A}$ are negative

↳ force is compressive