Thermal Physics - I

Development of Kinetic Theory:

18th century

Anonymous theory: 1761 J. Black: observed same temperature for ice & water & conjectured about "latent" heat.

1797 J. Watt: converted heat → work as steam engine

1797 B. Thompson, C. Rumford: work → heat

Caloric fluid theory: 1783 A. Lavoisier: conjectured heat as invisible fluid.

1824 S. Carnot: Carnot engine → Thermochemistry.

19th century

Kinetic theory: 1738 D. Bernoulli: molecular theory of fluid

1847 J.P. Joule, J. von Mayer, H. von Helmholtz: heat & work equivalent form of energy.

1850 R. Clausius: (a) showed that "caloric fluid theory" is reconciled in "kinetic theory", (b) First law of Thermodynamics, (c) defined "entropy".

1854 Thomson or Lord Kelvin → Thermodynamics

Experimental gas laws:

1662 Boyle's law: $P \propto V^{-1}$

1802 Charle's law: $V \propto T$

1802 Gay-Lussac's law:

International scale of temperature

Lord Kelvin introduced lowest temperature independent of property of substance

absolute zero	$-273^\circ C$ or $0K$	
ice point	$0^\circ C$ or $273K$	
steam point	$100^\circ C$ or $373K$	

Sulphur point	$444.6^\circ C$
Antimony point	$630.5^\circ C$
Silver point	$960.8^\circ C$
Gold point	$1063.8^\circ C$

Human body temperature 98.4°F ⟺ 36.9°C (remember, least count is 0.1°C)

relation between C, F, R (Reumer scale)

$$\frac{C}{5} = \frac{F-32}{9} = \frac{R}{4}.$$

Basics of Thermometry

a) Liquid Thermometer: Hg in glass, 6's max-min, Beckmann, Index

b) Gas Thermometer: Callendar's Air, Hydrogen

c) Metal Thermometer: Platinum resistance,

d) Thermoelectric Thermometer : thermocouple generates e.m.f.

e) Radiation Thermometer :

principle of thermometry: let A = thermometric property

for uniform variation of A with temperature T

$A_T = A_0(1+\alpha T)$, A_0 = value of A at 0°C

A_{100} = value of A at 100°C

$A_{100} = A_0(1+100\alpha)$

$$\therefore \boxed{T = 100\frac{A_T - A_0}{A_{100} - A_0}}$$

What is A ? If you take simple Hg-in glass thermometer then A = length of Hg column. For Pt-resistance thermometer A = resistance R of Pt. For constant volume gas thermometer A = pressure of air.

Hg in glass thermometer

pros (a) liquid range [−38.87°C, 356°C]

(b) low thermal capacity & high conductivity

(c) uniform expansion, (d) shining liquid (easy to see)

cons (a) high specific gravity (less sensitive)

(b) high surface tension (motion is jerkey)

unsuitable for low T.

Alcohol thermometer

pros (a) liquid range $[-112°C, 78°C]$

(b) high coefficient of expansion (more sensitive)

(c) low surface tension (motion is smooth)

cons unsuitable for high temperature.

Gas thermometer (a) Very high coefficient of expansion (more sensitive)

(b) low thermal capacity, low specific gravity

(c) constant volume / constant pressure thermometer.

Platinum Resistance thermometer : Resistance smooth in range $[-200°C, 1200°C]$

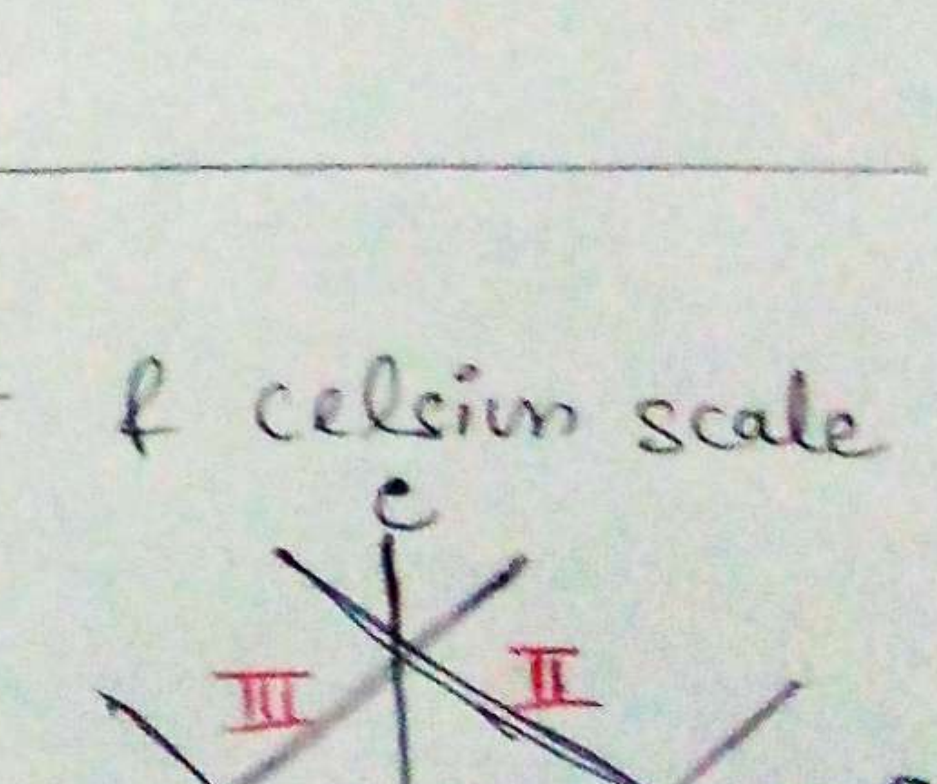
least count $= 0.01°C$

Low temperature Thermometry	High temperature thermometry
0°C to 630°C → all	630°C to 1000°C → liquid, gas, resistance, thermocouple.
−20°C to 0°C → liquid, gas, resistance, thermocouple, vapour pressure.	1000°C to 1600°C → gas, thermocouple.
−272°C to −20°C → resistance, vapour pressure, magnetic	1600°C to 3000°C → thermocouple, pyrometer.
below −272°C → magnetic	

HW

1. At what temperature do the Fahrenheit & Celsius scale give the same reading?

2. In figure beside, which line represents $\frac{C}{5} = \frac{F-32}{9}$?



3. In a constant volume gas thermometer, pressure of air at 0°C is 80 cm & at 100°C is 109.3 cm. Calculate the temperature of a hot bath, in which when the thermometer is immersed shows a pressure 100 cm.

Calorimetry Definition of Calorie (heat) ⇒ quantity of heat needed to raise temperature of 1 gm of water by $1^\circ C$. But heat $5^\circ C \rightarrow 6^\circ C \neq 80^\circ C \rightarrow 81^\circ C$.

Mean calorie heat $[0^\circ C \rightarrow 100^\circ C]/100$.

$15^\circ C$ Calorie heat $14.5^\circ C \rightarrow 15.5^\circ C$

B. Th. U. quantity of heat needed to raise temperature of 1 lb of water by $1^\circ F$.

1 B. Th. U. = 252 cals

1. C. H. U. = 453.6 cals.
(centrigrad heat unit)

$$H = m\, s\, T = c\, T$$

H → heat; m → mass of substance; s → specific heat; T → temperature; c → thermal capacity

Basic principle of Calorimetry conservation of heat energy or sum total of (body + heat bath) is conserved.

Specific heat of solid: Method of mixture, Copper block calorimeter, Electrical method (Lindemann calorimeter), Latent heat (Bunsen ice calorimeter)

Specific heat of liquid: Method of mixture, Bunsen ice calorimeter, Method of cooling, Nernst calorimeter, continuous flow calorimeter.

Specific heat of gas: # why constant pressure or volume?

$c = \frac{dQ}{dT}$ → suppose system expands → temperature falls to prevent, dQ heat added. so $dT = 0$.

$c = \frac{dQ}{0} \rightarrow \infty$

→ suppose system compresses → temperature rise dT without the need of dQ ∴ $dQ = 0$

$c = \frac{0}{dT} = 0$.

$\therefore \quad C_p = \left(\frac{dQ}{dT}\right)_p , \quad C_v = \left(\frac{dQ}{dT}\right)_v$

definition: at P = constant, increase temperature of 1 gm of gas through 1°. If 1 gm molecule of gas is taken → molar specific heat. $C_p = M c_p$

$C_p > C_v$? # heat transfer at V = constant, $dV = 0$. $dW = PdV = 0$
no work done by the gas.
So heat supplied transformed to thermal energy

$C_p - C_v = \frac{R}{J}$ (heat unit)

$\boxed{C_p - C_v = R}$

heat transfer at P = constant, $dW = PdV \neq 0$.
So heat supplied → thermal energy + external work.

Isothermal transformation : T = constant $\boxed{PV = RT = \text{constant}}$

Adiabatic transformation : Q = constant, $dQ = C_v dT + PdV$ — ①

Now from $PV = RT$, $PdV + VdP = RdT = (C_p - C_v)dT$

put dT in ① : $dQ = C_v \frac{PdV + VdP}{C_p - C_v} + PdV = 0$ (as Q = constant)

$\therefore \quad C_v VdP + C_p PdV = 0$

or $\frac{C_p}{C_v}\frac{dV}{V} = -\frac{dP}{P}$, (put $\gamma = \frac{C_p}{C_v}$)

Integrating both sides, $\gamma \ln V = -\ln P + \ln C$.

$\boxed{PV^\gamma = \text{constant}}$

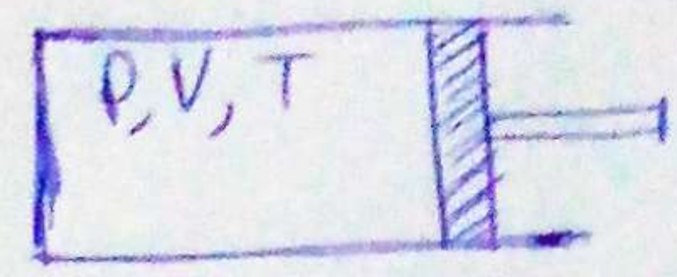
Corollary: PT relation : put $PV = RT$, $P\left(\frac{RT}{P}\right)^\gamma = C \Rightarrow P^{1-\gamma} T^\gamma = \text{constant}$

VT relation: put $PV = RT$, $\frac{RT}{V} V^\gamma = C \Rightarrow V^{\gamma-1} T = \text{constant}$

CW

Suppose dry air is enclosed in a cylinder fitted with piston. Initial temperature of air is $30^\circ C$. Find the change in temperature if the gas is compressed (a) slowly, (b) suddenly to one-half of its volume? What'll be the pressure?

(a) piston moves inwards → gas compresses



↓

no change in temperature (isothermal) ← heat goes to surrounding by conducting wall slowly ← temperature rises

$T = 30°C$

(b) Temperature rise rate >>> heat diffusion rate to surrounding

adiabatic process → no Q transfer.

So $P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$ & given $V_2 = \frac{V_1}{2}$

$\therefore P_2 = 2^{\gamma} P_1 = 2^{1.4} P_1 = 2.6 P_1 = \underline{2.6 \text{ atm}}$ when $P_1 = \underline{1 \text{ atm}}$.

Compare with isothermal, $P_2 = 2P_1 = \underline{2 \text{ atm}}$.

Again from TV relation, $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$\therefore T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 2^{0.4} T_1 = 1.319 \times (273+30) K$

$= 399.7 K = (399.7 - 273)°C = \underline{127°C}$.

HW 4. Air in a Wilson's cloud chamber at 20°C is abruptly expanded to 1.4 times its initial volume. Calculate the final temperature. Given $\gamma = 1.4$.

5. At 10^6 dynes/cm^2 pressure, a gas ($\gamma = 1.4$) expands isothermally until its volume is double of the initial volume. Then it adiabatically expands until its volume is redoubled. Calculate the final pressure of the gas.