DefenceGuru

(Physics)

4 Heat and Thermodynamics

4.1: Heat and Temperature

Temp. scales: $F = 32 + \frac{9}{5}C, \quad K = C + 273.16$

Ideal gas equation: $pV = nRT, \quad n$: number of moles

van der Waals equation: $\left(p + \frac{a}{V^2}\right)(V - b) = nRT$

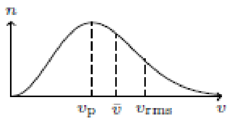
Thermal expansion: $L = L_0(1 + \alpha\Delta T)$,
$A = A_0(1 + \beta\Delta T)$, $V = V_0(1 + \gamma\Delta T)$, $\gamma = 2\beta = 3\alpha$

Thermal stress of a material: $\frac{F}{A} = Y\frac{\Delta l}{l}$

4.2: Kinetic Theory of Gases

General: $M = mN_A$, $k = R/N_A$

Maxwell distribution of speed:



RMS speed: $v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$

Average speed: $\bar{v} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}}$

Most probable speed: $v_p = \sqrt{\frac{2kT}{m}}$

Pressure: $p = \frac{1}{3}\rho v_{rms}^2$

Equipartition of energy: $K = \frac{1}{2}kT$ for each degree of freedom. Thus, $K = \frac{f}{2}kT$ for molecule having f degrees of freedoms.

Internal energy of n moles of an ideal gas is $U = \frac{f}{2}nRT$.

4.3: Specific Heat

Specific heat: $s = \frac{Q}{m\Delta T}$

Latent heat: $L = Q/m$

Specific heat at constant volume: $C_v = \left.\frac{\Delta Q}{n\Delta T}\right|_V$

Specific heat at constant pressure: $C_p = \left.\frac{\Delta Q}{n\Delta T}\right|_p$

Relation between C_p and C_v: $C_p - C_v = R$

Ratio of specific heats: $\gamma = C_p/C_v$

Relation between U and C_v: $\Delta U = nC_v\Delta T$

Specific heat of gas mixture:

$$C_v = \frac{n_1C_{v1} + n_2C_{v2}}{n_1 + n_2}, \quad \gamma = \frac{n_1C_{p1} + n_2C_{p2}}{n_1C_{v1} + n_2C_{v2}}$$

Molar internal energy of an ideal gas: $U = \frac{f}{2}RT$, $f = 3$ for monatomic and $f = 5$ for diatomic gas.

4.4: Theromodynamic Processes

First law of thermodynamics: $\Delta Q = \Delta U + \Delta W$

Work done by the gas:

$$\Delta W = p\Delta V, \quad W = \int_{V_1}^{V_2} p\mathrm{d}V$$

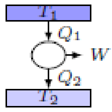
$$W_{\text{isothermal}} = nRT\ln\left(\frac{V_2}{V_1}\right)$$

$$W_{\text{isobaric}} = p(V_2 - V_1)$$

$$W_{\text{adiabatic}} = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

$$W_{\text{isochoric}} = 0$$

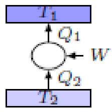
Efficiency of the heat engine:



$$\eta = \frac{\text{work done by the engine}}{\text{heat supplied to it}} = \frac{Q_1 - Q_2}{Q_1}$$

$$\eta_{\text{carnot}} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Coeff. of performance of refrigerator:



$$\text{COP} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

Entropy: $\Delta S = \frac{\Delta Q}{T}$, $S_f - S_i = \int_i^f \frac{\Delta Q}{T}$

Const. $T : \Delta S = \frac{Q}{T}$, Varying $T : \Delta S = ms\ln\frac{T_f}{T_i}$

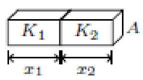
Adiabatic process: $\Delta Q = 0$, $pV^\gamma = \text{constant}$

4.5: Heat Transfer

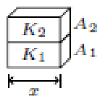
Conduction: $\frac{\Delta Q}{\Delta t} = -KA\frac{\Delta T}{x}$

Thermal resistance: $R = \frac{x}{KA}$

$$R_{\text{series}} = R_1 + R_2 = \frac{1}{A}\left(\frac{x_1}{K_1} + \frac{x_2}{K_2}\right)$$

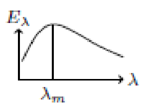


$$\frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{x}(K_1A_1 + K_2A_2)$$



Kirchhoff's Law: $\frac{\text{emissive power}}{\text{absorptive power}} = \frac{E_{\text{body}}}{a_{\text{body}}} = E_{\text{blackbody}}$

Wien's displacement law: $\lambda_m T = b$



Stefan-Boltzmann law: $\frac{\Delta Q}{\Delta t} = \sigma eAT^4$

Newton's law of cooling: $\frac{\mathrm{d}T}{\mathrm{d}t} = -bA(T - T_0)$

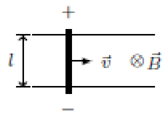
5.7: Electromagnetic Induction

Magnetic flux: $\phi = \oint \vec{B} \cdot \mathrm{d}\vec{S}$

Faraday's law: $e = -\frac{\mathrm{d}\phi}{\mathrm{d}t}$

Lenz's Law: Induced current create a B-field that opposes the change in magnetic flux.

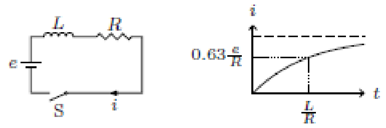
Motional emf: $e = Blv$



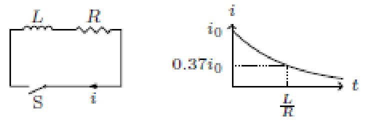
Self inductance: $\phi = Li, \quad e = -L\frac{\mathrm{d}i}{\mathrm{d}t}$

Self inductance of a solenoid: $L = \mu_0 n^2(\pi r^2 l)$

Growth of current in LR circuit: $i = \frac{e}{R}\left[1 - e^{-\frac{t}{L/R}}\right]$



Decay of current in LR circuit: $i = i_0 e^{-\frac{t}{L/R}}$



Time constant of LR circuit: $\tau = L/R$

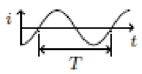
Energy stored in an inductor: $U = \frac{1}{2}Li^2$

Energy density of B field: $u = \frac{U}{V} = \frac{B^2}{2\mu_0}$

Mutual inductance: $\phi = Mi, \quad e = -M\frac{\mathrm{d}i}{\mathrm{d}t}$

EMF induced in a rotating coil: $e = NAB\omega \sin \omega t$

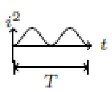
Alternating current:



$i = i_0 \sin(\omega t + \phi), \quad T = 2\pi/\omega$

Average current in AC: $\bar{i} = \frac{1}{T}\int_0^T i \, \mathrm{d}t = 0$

RMS current: $i_{\mathrm{rms}} = \left[\frac{1}{T}\int_0^T i^2 \, \mathrm{d}t\right]^{1/2} = \frac{i_0}{\sqrt{2}}$



Energy: $E = {i_{\mathrm{rms}}}^2 RT$

Capacitive reactance: $X_c = \frac{1}{\omega C}$

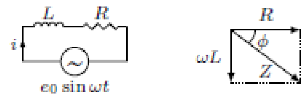
Inductive reactance: $X_L = \omega L$

Imepedance: $Z = e_0/i_0$

RC circuit:

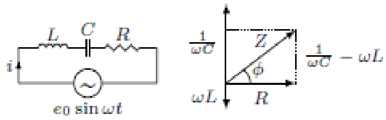
$$Z = \sqrt{R^2 + (1/\omega C)^2}, \quad \tan\phi = \frac{1}{\omega CR}$$

LR circuit:



$$Z = \sqrt{R^2 + \omega^2 L^2}, \quad \tan\phi = \frac{\omega L}{R}$$

LCR Circuit:

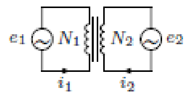


$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}, \quad \tan\phi = \frac{\frac{1}{\omega C} - \omega L}{R}$$

$$\nu_{\mathrm{resonance}} = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

Power factor: $P = e_{rms} i_{rms} \cos\phi$

Transformer: $\frac{N_1}{N_2} = \frac{e_1}{e_2}, \; e_1 i_1 = e_2 i_2$



Speed of the EM waves in vacuum: $c = 1/\sqrt{\mu_0 \epsilon_0}$