Formula Sheet for Physics 251

Constants

$R = 8.3145 \ \frac{\text{J}}{\text{m} \cdot \text{K}}$

$N_A = 6.02 \times 10^{23}$

$k_B = \frac{R}{N_A} = 1.38 \times 10^{-23} \ \frac{\text{J}}{\text{m} \cdot \text{K}}$

$e = 1.602 \times 10^{-19}$ C

$k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}$

$\mu_0 = 4\pi \times 10^{-7} \ \frac{\text{T} \cdot \text{m}}{\text{A}}$

$c = 3 \times 10^8 \ \frac{\text{m}}{\text{s}}$

Thermal Expansion

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

$\beta = 3\alpha$

Heat

$Q = mc\Delta T$

$Q = \pm mL$

$Q = nC_V \Delta T$

$Q = nC_P \Delta T$

Heat Current

$H = k\frac{A}{L}\left(T_H - T_C\right)$

$H = Ae\sigma T^4$

Quantities

Work

$W = \int_{V_i}^{V_f} P dV$

Isochoric Processes

$W = 0$

$Q = nC_V \Delta T$

* $\Delta U = nC_V \Delta T$

$m_{tot} = nM$

$M = N_A m$

$N = N_A n$

Ideal gases

* $PV = nrT$
* $PV = NkT$
* $v_{RMS} = \sqrt{\frac{3RT}{M}}$
* $C_V = \frac{3}{2}R$ (monatomic)
* $C_V = \frac{5}{2}R$ (diatomic)
* $C_P = C_V + R$

Isobaric Processes

$W = P\Delta V$

$Q = nC_P \Delta T$

* $\Delta U = nC_V \Delta T$

Isothermal Processes

* $W = nRT \ln\left(\frac{V_f}{V_i}\right)$
* $Q = nRT \ln\left(\frac{V_f}{V_i}\right)$
* $\Delta U = 0$

Adiabatic Processes

* $W = -nC_V \Delta T$

$Q = 0$

* $\Delta \text{U} = nC_V \Delta T$
* $P_1 V_l^{\gamma} = P_2 V_2^{\gamma}$
* $T_1 V_l^{\gamma-1} = T_2 V_2^{\gamma-1}$

$\gamma = \frac{C_P}{C_V}$

Cyclic Processes

$W = Q$

$\Delta U = 0$

Heat Engines

$W = Q_H + Q_C$

$e = \frac{W}{Q_H}$

$e_c = 1 - \frac{T_C}{T_H}$

Refrigerators

$W = Q_H + Q_C$

$K = \frac{|Q_C|}{|W|}$

$K_c = \frac{T_C}{T_H - T_C}$

Force, Field, Energy and Potential

$\vec{F} = q\vec{E}$

$\Delta U = q\Delta V$

$V_{ab} = \int_a^b \vec{E} \cdot d\vec{l}$

$\vec{E} = -\nabla V$

1 Point Charge

$\vec{E} = k\frac{q}{r^2}\hat{r}$

$V = k\frac{q}{r}$

2 Point Charges

$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$

$U = k\frac{q_1 q_2}{r}$

Distributed Charge

$\vec{E} = \int k\frac{dq}{r^2}\hat{r}$

$V = \int k\frac{dq}{r}$

Many Sources

$\vec{E}_T = \sum_i \vec{E}_i$

$U_T = \sum_{pairs} U_{ij}$

"Elementary" *E* Fields

$\vec{E} = k\frac{Q}{r^2}\hat{\text{r}}$ sphere

$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}$ line

$\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$ plane

$\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$ conducting surface

Capacitors

$C = \frac{Q}{V}$

$C_T = \sum_i C_i$ parallel

$\frac{1}{C_T} = \sum_i \frac{1}{C_i}$ series

$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$

† $C = \varepsilon_0 \frac{A}{d}$

† $|E| = \frac{V}{d} = \frac{\sigma}{\varepsilon_0}$

Flux and Gauss's Law

$\varphi = \iint \vec{E} \cdot d\vec{a}$

$\varphi_{\text{closed}} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$

Current and Current Density

$I = \frac{dq}{dt}$

$I = \iint \vec{J} \cdot d\vec{a}$

$\vec{J} = nqv_d$

* indicates formulas that are specific to ideal gases

† indicates formulas that are specific to parallel-plate capacitors

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Ohm's Law

$\vec{E} = \rho\vec{J}$

$V = IR$

Resistivity and Resistance

$R = \int \rho \frac{dL}{A}$

$\rho = \rho_0[1 + \alpha(T - T_0)]$

Uniform Currents only

$|E| = \frac{V}{L}$

$R = \rho\frac{L}{A}$

$|J| = \frac{I}{A}$

Electric Power

$P = IV$

$P = I^2 R$

$P = \frac{V^2}{R}$

Real Batteries

$V = \mathcal{E} - Ir$

Addition of Resistors

$R_T = R_1 + R_2 + \ldots$ series

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ parallel

Kirchoff's rules

$\sum_{loop} V = 0$

$\sum_{node} I = 0$

RC circuits (charging)

$I = I_i e^{-\frac{t}{\tau}}$

$Q = Q_f\left(1 - e^{-\frac{t}{\tau}}\right)$

$\tau = RC$

RC circuits (discharging)

$I = I_i e^{-\frac{t}{\tau}}$

$Q = Q_i e^{-\frac{t}{\tau}}$

$\tau = RC$

Magnetic Force and Torque

$\vec{F} = q\vec{v} \times \vec{B}$

$d\vec{F} = Id\vec{l} \times \vec{B}$

$\tau = \vec{\mu} \times \vec{B}$

$U = -\vec{\mu} \cdot \vec{B}$

Cyclotron Motion

$R = \frac{mv}{qB}$

$T = \frac{2\pi m}{qB}$

$\omega_c = \frac{qB}{m}$

Flux and Gauss's Law for Magnetism

$\varphi = \iint \vec{B} \cdot d\vec{a}$

$\varphi_{\text{closed}} = 0$

Sources of Magnetic Fields

$B = \frac{\mu_0}{4\pi}\frac{q\vec{v} \times \hat{r}}{r^2}$

$\vec{B} = \int \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$

$|B| = \frac{\mu_0 I}{2\pi r}$ ∞ straight wire

$|B| = \frac{\mu_0 I}{2R}$ center of loop

$|B| = \mu_0 nI$ ∞ solenoid

$|B| = \frac{\mu_0 NI}{2\pi r}$ toroidal solenoid

Ampere's Law

$\oint \vec{B} \cdot d\vec{l} = \mu_0\left(I_{\text{enc}} + I_d\right)$

where

$I_d = \varepsilon_0 \frac{d\varphi_E}{dt}$

Faraday's Law

$\mathcal{E} = -\frac{d\varphi_B}{dt}$

or

$\oint_C \vec{E} \cdot d\vec{l} = \iint_S \vec{B} \cdot d\vec{a}$

Mutual Inducance

$M = \frac{N_1\varphi_{B1}}{I_2} = \frac{N_2\varphi_{B2}}{I_1}$

$\mathcal{E}_1 = -M\frac{dI_2}{dt}$

$\mathcal{E}_2 = -M\frac{dI_1}{dt}$

Self Inductance

$L = \frac{N\varphi_B}{I}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U = \frac{1}{2}LI^2$

RL Circuits (charging)

$I = I_f\left(1 - e^{-\frac{t}{\tau}}\right)$

$V_L = V_0 e^{-\frac{t}{\tau}}$

$\tau = \frac{L}{R}$

RL Circuits (discharging)

$I = I_i e^{-\frac{t}{\tau}}$

$V_L = V_i e^{-\frac{t}{\tau}}$

$\tau = \frac{L}{R}$

AC Circuits (general)

$X_L = \omega L$

$X_C = \frac{1}{\omega C}$

$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$

$\tan\varphi = \frac{X_L - X_C}{R}$

$I = I_0 \cos\omega t$

$V = V_0 \cos(\omega t + \varphi)$

$V_0 = I_0 Z$

$V_{rms} = \frac{V_0}{\sqrt{2}}$

$I_{rms} = \frac{I_0}{\sqrt{2}}$

$V_{R,\max} = IR$

$V_{L,\max} = IX_L$

$V_{C,\max} = IX_C$

$P = \frac{1}{2}I_0^2 R = \frac{1}{2}I_0^2 Z\cos\varphi$

AC Circuits (resonance)

$\varphi = 0$

$Z = R$

$\omega = \frac{1}{\sqrt{LC}}$

$X_L = X_C$

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Light

$E_{\max} = cB_{\max}$

$c = \dfrac{1}{\sqrt{\varepsilon_0 \mu_0}}$

$c = \lambda f$

$\vec{S} = \dfrac{1}{\mu_0}\vec{E} \times \vec{B}$

$I = S_{av} = \dfrac{E_{\max} B_{\max}}{2\mu_0}$

$p_{rad} = \dfrac{S_{av}}{c}$

Propagation of Light

$n = \dfrac{c}{v}$

$\lambda = \dfrac{\lambda_0}{n}$

$\theta_r = \theta_a$

$n_a \sin\theta_a = n_b \sin\theta_b$

$\theta_c = \dfrac{n_b}{n_a}$ (TIR)

$I = I_0 \cos^2 \varphi$

Focal Lengths

$f = \dfrac{R}{2}$

$\dfrac{1}{f} = (n-1)\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$

Image Location

$\dfrac{1}{f} = \dfrac{1}{s} + \dfrac{1}{s'}$

Lateral and Angular Magnification

$m = \dfrac{y'}{y} = -\dfrac{s'}{s}$

$m_T = m_1 m_2 \ldots$

$M = \dfrac{\theta'}{\theta}$

$M = \dfrac{25}{f(\text{cm})}$ Magnifier

$M = -\dfrac{f_{objective}}{f_{eyepiece}}$ Telescope

Cameras

f - number $= \dfrac{f}{D}$

Eyeglasses

power $= \dfrac{1}{f}$ diopters

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