

Pregled formula iz *Fizike 1* i *Fizike 2*

FER/fizika

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1 Kinematika čestice

Položaj $\vec{r}[t]$, brzina $\vec{v}[t]$ i akceleracija $\vec{a}[t]$:

$$\vec{v}[t] = \frac{d}{dt}\vec{r}[t] \quad \vec{r}[t] = \vec{r}[t_0] + \int_{t_0}^t \vec{v}[t'] dt'$$

$$\vec{a}[t] = \frac{d}{dt}\vec{v}[t] \quad \vec{v}[t] = \vec{v}[t_0] + \int_{t_0}^t \vec{a}[t'] dt'$$

Gibanje stalnom brzinom \vec{v} :

$$\vec{r}[t] = \vec{r}[t_0] + \vec{v}(t - t_0)$$

Gibanje stalnom akceleracijom \vec{a} :

$$\vec{v}[t] = \vec{v}[t_0] + \vec{a}(t - t_0)$$

$$\vec{r}[t] = \vec{r}[t_0] + \vec{v}[t_0](t - t_0) + \frac{\vec{a}}{2}(t - t_0)^2$$

Kosi hitac uz $\vec{a} = -g \hat{j}$ u $z = 0$ ravnini:

$$\vec{r}[0] = 0 \quad \vec{v}[0] = v_0(\cos \alpha \hat{i} + \sin \alpha \hat{j})$$

$$\vec{v}[t] = v_0 \cos \alpha \hat{i} + (v_0 \sin \alpha - gt) \hat{j}$$

$$\vec{r}[t] = v_0 t \cos \alpha \hat{i} + \left(v_0 t \sin \alpha - \frac{g}{2}t^2\right) \hat{j}$$

$$y[x] = x \tan \alpha - \frac{gx^2}{2v_0^2}(1 + \tan^2 \alpha)$$

Gibanje po kružnici polumjera r u $z = 0$ ravnini:

$$\vec{r}[t] = r(\cos \varphi[t] \hat{i} + \sin \varphi[t] \hat{j})$$

$$\vec{v}[t] = r\omega[t](-\sin \varphi[t] \hat{i} + \cos \varphi[t] \hat{j}) \quad \omega[t] = \frac{d}{dt}\varphi[t]$$

$$\vec{a}[t] = -(\omega[t])^2 \vec{r}[t] + \frac{\alpha[t]}{\omega[t]} \vec{v}[t] \quad \alpha[t] = \frac{d}{dt}\omega[t]$$

uz definiciju $\vec{\omega} = \omega \hat{k}$, $\vec{\alpha} = \alpha \hat{k}$ i $\vec{a} = \vec{a}_{\text{rad.}} + \vec{a}_{\text{tang.}}$:

$$\vec{v} = \vec{\omega} \times \vec{r} \quad \vec{a}_{\text{rad.}} = \vec{\omega} \times \vec{v} \quad \vec{a}_{\text{tang.}} = \vec{\alpha} \times \vec{r}$$

Kruženje stalnom kutnom brzinom ω :

$$\varphi[t] = \varphi[t_0] + \omega(t - t_0)$$

Kruženje stalnom kutnom akceleracijom α :

$$\omega[t] = \omega[t_0] + \alpha(t - t_0)$$

$$\varphi[t] = \varphi[t_0] + \omega[t_0](t - t_0) + \frac{\alpha}{2}(t - t_0)^2$$

2 Dinamika čestice

Količina gibanja i kinetička energija:

$$\vec{p} = m\vec{v} \quad E_{\text{kin.}} = \frac{mv^2}{2}$$

Jednadžba gibanja:

$$\frac{d}{dt}\vec{p} = \vec{F}$$

$$\vec{F} = m\vec{a} \quad (m = \text{konst.})$$

Impuls sile:

$$\vec{I} = \int_{t_1}^{t_2} \vec{F}[t] dt = \vec{p}[t_2] - \vec{p}[t_1]$$

Kutna količina gibanja i moment sile:

$$\vec{L} = \vec{r} \times \vec{p} \quad \vec{M} = \frac{d}{dt}\vec{L} = \vec{r} \times \vec{F}$$

Rad, kinetička energija, snaga:

$$dW = \vec{F} \cdot d\vec{r} \quad W_{12} = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}[\vec{r}] \cdot d\vec{r}$$

$$\Delta W = \Delta E_{\text{kin.}} \quad P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$$

Konzervativne sile ($\oint \vec{F}[\vec{r}] \cdot d\vec{r} = 0$), potencijalna energija:

$$E_{\text{pot.}}[\vec{r}] = E_{\text{pot.}}[\vec{r}_0] - \int_{\vec{r}_0}^{\vec{r}} \vec{F}[\vec{r}'] \cdot d\vec{r}'$$

$$\vec{F}[\vec{r}] = -\nabla E_{\text{pot.}}[\vec{r}]$$

$$\Delta E_{\text{kin.}} + \Delta E_{\text{pot.}} = 0$$

$$\text{sila opruge:} \quad F[x] = -kx \quad E_{\text{pot.}}[x] = \frac{1}{2}kx^2$$

$$\text{sila teža:} \quad \vec{G} = -mg \hat{j} \quad E_{\text{pot.}}[y] = mgy$$

Nekonzervativne sile ($\oint \vec{F}[\vec{r}] \cdot d\vec{r} \neq 0$):

$$\text{trenje klizanja:} \quad F = \mu N$$

Centripetalna sila:

$$\vec{F}_{\text{CP}} = m\vec{a}_{\text{rad.}} = -m\omega^2 \vec{r} \quad F_{\text{CP}} = \frac{mv^2}{r}$$

3 Sudar dviju čestica

Veličine označene s ' odnose se na stanje nakon sudara:

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = m_1 \vec{v}'_1 + m_2 \vec{v}'_2$$

$$E_{\text{kin.}} = \frac{m_1 v_1^2 + m_2 v_2^2}{2} \quad E'_{\text{kin.}} = \frac{m_1 v'^2_1 + m_2 v'^2_2}{2}$$

$$\text{koeficijent restitucije: } k = \frac{|\vec{v}'_1 - \vec{v}'_2|}{|\vec{v}_1 - \vec{v}_2|}$$

$$Q = E'_{\text{kin.}} - E_{\text{kin.}} = -(1 - k^2) \frac{m_1 m_2 |\vec{v}_1 - \vec{v}_2|^2}{2(m_1 + m_2)}$$

Savršeno neelastični sudar ($k = 0$):

$$\vec{v}'_1 = \vec{v}'_2 = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2}$$

Savršeno elastični čeon sudar ($k = 1$):

$$\vec{v}'_1 = \frac{(m_1 - m_2) \vec{v}_1 + 2m_2 \vec{v}_2}{m_1 + m_2}$$

$$\vec{v}'_2 = \frac{(m_2 - m_1) \vec{v}_2 + 2m_1 \vec{v}_1}{m_1 + m_2}$$

Općenit čeon sudar, $\vec{v}'_2 - \vec{v}'_1 = -k(\vec{v}_2 - \vec{v}_1)$:

$$\vec{v}'_1 = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2} - k \frac{m_2 (\vec{v}_1 - \vec{v}_2)}{m_1 + m_2}$$

$$\vec{v}'_2 = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2} - k \frac{m_1 (\vec{v}_2 - \vec{v}_1)}{m_1 + m_2}$$

4 Sustav čestica

Masa i centar mase sustava, $i = 1, \dots, N$:

$$m = \sum_i m_i \quad \vec{r}_{\text{cm}} = \frac{1}{m} \sum_i m_i \vec{r}_i$$

$$\vec{v}_{\text{cm}} = \frac{d}{dt} \vec{r}_{\text{cm}} \quad \vec{a}_{\text{cm}} = \frac{d}{dt} \vec{v}_{\text{cm}}$$

Količina gibanja sustava:

$$\vec{p} = \sum_i \vec{p}_i = m \vec{v}_{\text{cm}} \quad \frac{d}{dt} \vec{p} = m \vec{a}_{\text{cm}} = \sum_i \vec{F}_i = \vec{F}$$

Kutna količina gibanja sustava:

$$\vec{L} = \sum_i \vec{L}_i \quad \frac{d}{dt} \vec{L} = \sum_i \vec{M}_i = \vec{M}$$

Kinetička energija sustava:

$$E_{\text{kin.}} = \frac{1}{2} \sum_i m_i v_i^2 = \frac{1}{2} m v_{\text{cm}}^2 + \frac{1}{2} \sum_i m_i |\vec{v}_i - \vec{v}_{\text{cm}}|^2$$

5 Kruto tijelo

Vrtnja oko čvrste osi (s je udaljenost od osi):

$$I_z = \sum_i m_i s_i^2 \quad s = \sqrt{x^2 + y^2}$$

teorem o paralelnim osima: $I_z = I_{\text{cm}} + m d^2$

teorem o okomitim osima: $I_z = I_x + I_y$

$$L_z = I_z \omega \quad \frac{d}{dt} L_z = I_z \alpha = M_z$$

$$E_{\text{kin.}} = \frac{1}{2} I_z \omega^2 \quad P = M_z \omega \quad dW = M_z d\varphi$$

Vrtnja uz translaciju:

$$E_{\text{kin.}} = \frac{1}{2} m v_{\text{cm}}^2 + \frac{1}{2} I_{\text{cm}} \omega^2$$

Vrtnja tijela oko glavne osi (osi simetrije):

$$\vec{L} = I_{\text{cm}} \vec{\omega}$$

Momenti tromosti I_{cm} u odnosu na os kroz centar mase nekih simetričnih tijela:

Tanki prsten, os \perp na ravninu prstena: $m R^2$

Okrugla ploča, os \perp na ravninu ploče: $\frac{1}{2} m R^2$

Šuplji valjak, os simetrije: $\frac{1}{2} m (R_1^2 + R_2^2)$

Homogena kugla: $\frac{2}{5} m R^2$

Tanka šuplja kugla (sfera): $\frac{2}{3} m R^2$

Tanki štap duljine L , os \perp na štap: $\frac{1}{12} m L^2$

6 Gravitacija

Sila na česticu 1:

$$\vec{F}_{12} = -G_N \frac{m_1 m_2}{r_{12}^2} \hat{r}_{12} \quad \vec{r}_{12} = \vec{r}_2 - \vec{r}_1$$

Gravitacijsko polje i potencijal:

$$\vec{g}[\vec{r}] = -G_N \sum_i \frac{m_i (\vec{r} - \vec{r}_i)}{|\vec{r} - \vec{r}_i|^3} \quad \vec{F}[\vec{r}] = m \vec{g}[\vec{r}]$$

$$\phi[\vec{r}] = -G_N \sum_i \frac{m_i}{|\vec{r} - \vec{r}_i|} \quad E_{\text{pot.}}[\vec{r}] = m \phi[\vec{r}]$$

$$\vec{g}[\vec{r}] = -\nabla \phi[\vec{r}] \quad \vec{F}[\vec{r}] = -\nabla E_{\text{pot.}}[\vec{r}]$$

7 Neinerijski sustavi

Galileijeve transformacije (S' se giba brzinom v u smjeru x -osi):

$$x' = x - vt \quad y' = y \quad z' = z \quad t' = t$$

$$v'_x = v_x - v \quad v'_y = v_y \quad v'_z = v_z$$

Jednadžba gibanja (S' ubrzava akceleracijom \vec{a}_0 u odnosu na inercijski sustav S):

$$m \vec{a} = \vec{F} \quad m \vec{a}' = \vec{F} + \vec{F}'_1 \quad \vec{F}'_1 = -m \vec{a}_0$$

Centrifugalna i Coriolisova sila:

$$\vec{F}'_{\text{CF}} = m \omega^2 \vec{r} \quad \vec{F}'_{\text{COR}} = 2m \vec{v}' \times \vec{\omega}$$

8 Relativistička mehanika

Lorentzove transformacije (S' se giba brzinom v u smjeru x -osi, $\beta = v/c$):

$$x' = \frac{x - vt}{\sqrt{1 - \beta^2}} \quad y' = y \quad z' = z \quad t' = \frac{t - vx/c^2}{\sqrt{1 - \beta^2}}$$

kontrakcija duljine: $\Delta x = \Delta x_0 \sqrt{1 - \beta^2}$

dilatacija vremena: $\Delta t = \frac{\Delta t_0}{\sqrt{1 - \beta^2}}$

Transformacija brzine:

$$u'_x = \frac{u_x - v}{1 - vu_x/c^2} \quad u'_{y,z} = \frac{u_{y,z} \sqrt{1 - \beta^2}}{1 - vu_x/c^2}$$

Količina gibanja i energija čestice:

$$\vec{p} = \gamma m \vec{v} \quad E = \gamma mc^2 = mc^2 + E_{\text{kin.}}$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}} \quad \beta = \frac{v}{c}$$

$$E^2 = (pc)^2 + (mc^2)^2$$

9 Statika fluida

Tlak, uvjet ravnoteže fluida, uzgon:

$$p = \frac{dF}{dA} \quad dp = -\rho g dh \quad dF_U = \rho g dV$$

Hidrostatski tlak na dubini d ($\rho = \text{konst.}$):

$$p[d] = p_0 + \rho g d$$

Izotermna atmosfera ($p/\rho \propto T = \text{konst.}$):

$$p[h] = p_0 \exp \left[-\frac{\rho_0}{p_0} gh \right]$$

Površinska napetost:

$$\sigma = \frac{dW}{dS} = \frac{dF}{d\ell} \quad \Delta p = \sigma \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

Kapilarna elevacija:

$$h = \frac{2\sigma \cos \theta}{\rho g r}$$

10 Dinamika fluida

Jednadžba kontinuiteta, Bernoullijeva jednadžba:

$$q_v = \frac{dV}{dt} = Sv = \text{konst.} \quad p + \rho gh + \frac{\rho v^2}{2} = \text{konst.}$$

Viskozno trenje, Reynoldsov broj:

$$F_{\text{TR}} = \eta S \frac{dv}{dz} \quad \text{Re} = \frac{\rho v \ell}{\eta}$$

Poiseuilleov zakon:

$$v[r] = \frac{p_1 - p_2}{4\eta \ell} (R^2 - r^2) \quad q_v = \frac{\pi(p_1 - p_2)}{8\eta \ell} R^4$$

Stokesov zakon:

$$F_{\text{otpor}} = 6\pi\eta Rv$$

Turbulentno strujanje:

$$F_{\text{otpor}} = \frac{1}{2} C_0 S \rho v^2$$

11 Toplina i temperatura

Toplinsko rastezanje:

$$\ell = \ell_0 (1 + \alpha \Delta T) \quad \alpha = \frac{d\ell}{\ell_0 dT}$$

$$V = V_0 (1 + \gamma \Delta T) \quad \gamma = \frac{dV}{V_0 dT} \simeq 3\alpha$$

Jednadžba stanja idealnog plina:

$$pV = NkT = nRT = \frac{m}{M} RT$$

Vođenje topline ($\Delta T = T_2 - T_1 > 0$):

$$Q = \lambda \frac{\Delta T}{\Delta x} St \quad \Phi = \frac{dQ}{dt} = \lambda \frac{\Delta T}{\Delta x} S = \frac{\Delta T}{R} \quad R = \frac{\Delta x}{\lambda S}$$

12 Termodinamika

Prvi zakon:

$$d'Q = dU + d'W \quad d'W = p dV$$

Toplinski kapaciteti:

$$C_p = \frac{1}{n} \left(\frac{dQ}{dT} \right)_{p=\text{konst.}} \quad C_V = \frac{1}{n} \left(\frac{dQ}{dT} \right)_{V=\text{konst.}}$$

$$C_p - C_V = R \quad \kappa = \frac{C_p}{C_V} \quad c_p = \frac{C_p}{M} \quad c_V = \frac{C_V}{M}$$

Adijabatski proces ($d'Q = 0$):

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1} \right)^\kappa \quad \frac{T_1}{T_2} = \left(\frac{V_2}{V_1} \right)^{\kappa-1} = \left(\frac{p_1}{p_2} \right)^{(\kappa-1)/\kappa}$$

$$W_{12} = \frac{nR}{\kappa - 1} (T_1 - T_2) = \frac{p_1 V_1}{\kappa - 1} \left(1 - \frac{T_2}{T_1} \right)$$

Izotermni proces ($T = \text{konst.}$):

$$W_{12} = nRT \ln \frac{V_2}{V_1} = nRT \ln \frac{p_1}{p_2}$$

Carnotov kružni proces ($T_1 > T_2$):

$$W = Q_1 + Q_2 = |Q_1| - |Q_2| = Q_1 \left(1 - \frac{T_2}{T_1} \right)$$

$$\eta = \frac{W}{Q_1} = 1 - \frac{T_2}{T_1}$$

Entropija:

$$dS = \frac{d'Q}{T} \quad S_2 - S_1 = \int_1^2 \frac{d'Q}{T}$$

13 Kinetička teorija

Tlak, unutarnja energija i toplinski kapacitet idealnog plina:

$$p = \frac{Nm}{3V} \overline{v^2} = \frac{2N}{3V} \overline{E_{\text{kin.}}}$$

$$\overline{E_{\text{kin.}}} = \frac{i}{2} kT \quad U = \frac{i}{2} NkT = \frac{i}{2} nRT$$

$$C_p = \frac{i+2}{2} R \quad C_V = \frac{i}{2} R \quad \kappa = \frac{i+2}{i}$$

Maxwellova raspodjela:

$$N_v = \frac{dN}{dv} = \frac{4N}{\sqrt{\pi}} \left(\frac{m}{2kT} \right)^{3/2} v^2 \exp \left[-\frac{mv^2}{2kT} \right]$$

$$v_{\text{max}} = \sqrt{\frac{2RT}{M}} \quad \bar{v} = \sqrt{\frac{8RT}{\pi M}} \quad \sqrt{\overline{v^2}} = \sqrt{\frac{3RT}{M}}$$

Maxwell-Boltzmannova raspodjela:

$$N_E = \frac{dN}{dE} = \frac{2N}{\sqrt{\pi k^3 T^3}} \sqrt{E} \exp \left[-\frac{E}{kT} \right]$$

$$E_{\text{max}} = \frac{kT}{2} \quad \bar{E} = \frac{3}{2} kT$$

14 Elastičnost

Modul elastičnosti i gustoća energije:

$$\text{vlak:} \quad E = \frac{\sigma}{\delta_L} = \frac{F/S_0}{\Delta L/L_0} \quad u = \frac{E}{2} \delta_L^2 = \frac{\sigma^2}{2E}$$

$$\text{tlak:} \quad B = -\frac{p}{\delta_V} = -\frac{F/S_0}{\Delta V/V_0} \quad u = \frac{B}{2} \delta_V^2 = \frac{p^2}{2B}$$

$$\text{smik:} \quad G = \frac{\sigma}{\delta_\phi} = \frac{F/S}{\Delta \phi} \quad u = \frac{G}{2} \delta_\phi^2 = \frac{\sigma^2}{2G}$$

Poissonov omjer:

$$\mu = -\frac{\delta_{L\perp\sigma}}{\delta_{L\parallel\sigma}} \quad E = 3B(1 - 2\mu)$$

Konstanta torzije šipke:

$$D = \frac{dM}{d\varphi} = G \frac{R^4 \pi}{2L}$$

15 Titranje

Jednostavno harmoničko titranje, $ma = -kx$:

$$\frac{d^2}{dt^2} x[t] + \omega_0^2 x[t] = 0 \quad \omega_0^2 = \frac{k}{m}$$

$$x[t] = A \cos[\omega_0 t + \phi] \quad \omega_0 = 2\pi f = 2\pi/T$$

$$A = \sqrt{x[0]^2 + v[0]^2/\omega_0^2}$$

$$\cos \phi = \frac{x[0]}{A} \quad \sin \phi = -\frac{v[0]}{A\omega_0}$$

$$E = \frac{1}{2} k A^2 = \frac{1}{2} m \omega_0^2 A^2$$

Matematičko, fizičko i torziono njihalo:

$$\omega_{\text{mat.}}^2 = \frac{g}{\ell} \quad \omega_{\text{fiz.}}^2 = \frac{mg\ell_{\text{cm}}}{I_{\text{cm}} + m\ell_{\text{cm}}^2} = \frac{g}{\ell_{\text{red.}}} \quad \omega_{\text{torz.}}^2 = \frac{D}{I}$$

Prigušeno titranje, $ma = -kx - bv$, $\delta < \omega_0$:

$$\frac{d^2}{dt^2} x[t] + 2\delta \frac{d}{dt} x[t] + \omega_0^2 x[t] = 0 \quad \omega_0^2 = \frac{k}{m} \quad 2\delta = \frac{b}{m}$$

$$x[t] = Ae^{-\delta t} \cos[\omega t + \phi] \quad \omega = \sqrt{\omega_0^2 - \delta^2} = 2\pi f = 2\pi/T$$

$$\lambda = \delta T = \frac{2\pi\delta}{\omega} \quad Q = \frac{\omega}{2\delta}$$

Kritično prigušenje, $\delta = \omega_0$:

$$x[t] = e^{-\delta t} (x[0] + (v[0] + x[0]\delta)t)$$

Aperiodičko prigušenje, $\delta > \omega_0$, $q = \sqrt{\delta^2 - \omega_0^2}$:

$$x[t] = e^{-\delta t} \left(x[0] \text{ch}[qt] + \frac{v[0] + x[0]\delta}{q} \text{sh}[qt] \right)$$

Prisilno titranje, $ma = -kx - bv + F_p \cos[\omega t]$:

$$\frac{d^2}{dt^2} x[t] + 2\delta \frac{d}{dt} x[t] + \omega_0^2 x[t] = f_p \cos[\omega t]$$

$$\omega_0^2 = k/m \quad 2\delta = b/m \quad f_p = F_p/m$$

$$\text{partikularno rješenje:} \quad x[t] = A \cos[\omega t + \phi]$$

$$A = \frac{f_p}{\sqrt{(\omega_0^2 - \omega^2)^2 + 4\delta^2\omega^2}} \quad \text{tg } \phi = \frac{2\delta\omega}{\omega_0^2 - \omega^2}$$

$$\text{rezonancija amplitude:} \quad \omega_{\text{rez.}} = \sqrt{\omega_0^2 - 2\delta^2}$$

16 Mehanički valovi

Valna jednadžba ($y[x, t]$ je pomak iz ravnoteže):

$$\frac{\partial^2}{\partial x^2} y[x, t] - \frac{1}{v^2} \frac{\partial^2}{\partial t^2} y[x, t] = 0$$

$$\text{opće rješenje:} \quad y[x, t] = f[x \pm vt]$$

Harmonički val:

$$y[x, t] = A \cos[kx \pm \omega t + \phi]$$

$$\omega = 2\pi f = \frac{2\pi}{T} = kv = \frac{2\pi}{\lambda} v$$

Stojni val:

$$y[x, t] = A \cos[kx + \phi_1] \cos[\omega t + \phi_2]$$

Rubni uvjeti na stojni val u točkama razmaknutim L :

$$\text{čvrst-čvrst ili slob.-slob.:} \quad \lambda_n = 2L/n, \quad n = 1, 2, \dots$$

$$\text{čvrst-slob.:} \quad \lambda_n = 4L/(2n - 1), \quad n = 1, 2, \dots$$

Brzina i srednja snaga transverzalnog vala na užetu:

$$v^2 = \frac{F}{\mu} \quad \bar{P} = \frac{\mu}{2} \omega^2 A^2 v$$

Brzina zvuka longitudinalnog vala (zvuka) u tankom štapu, tekućini i plinu:

$$v_{\text{štap}}^2 = \frac{E}{\rho} \quad v_{\text{tek.}}^2 = \frac{B}{\rho} \quad v_{\text{plin}}^2 = \frac{\kappa p}{\rho} = \frac{\kappa RT}{M}$$

Srednja snaga i intenzitet zvuka:

$$\bar{P} = \frac{\rho}{2} \omega^2 A^2 S v \quad I = \frac{\bar{P}}{S} = \frac{(\Delta p_{\text{max}})^2}{2v\rho}$$

Razina jakosti buke:

$$L_{\text{dB}} = 10 \log_{10} \frac{I}{I_0} \quad I_0 = 10^{-12} \text{ W m}^{-2}$$

Dopplerov efekt:

$$f_p = f_i \frac{v_z - \hat{r}_{ip} \cdot \vec{v}_p}{v_z - \hat{r}_{ip} \cdot \vec{v}_i} \quad \vec{r}_{ip} = \vec{r}_p - \vec{r}_i$$

17 Elektromagnetizam

Lorentzova sila:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Elektrostatika (Coulombovo polje):

$$\begin{aligned} \vec{E}[\vec{r}] &= \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i(\vec{r} - \vec{r}_i)}{|\vec{r} - \vec{r}_i|^3} \\ &= \frac{1}{4\pi\epsilon_0} \int \frac{\rho[\vec{r}'](\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} dV' \end{aligned}$$

$$\Phi[\vec{r}] = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{|\vec{r} - \vec{r}_i|} \quad \vec{E}[\vec{r}] = -\nabla\Phi[\vec{r}]$$

Magnetostatika (Biot–Savartov zakon, $I = dq/dt$):

$$\vec{B}[\vec{r}] = \frac{\mu_0}{4\pi} \int \frac{I' d\vec{r}' \times (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3}$$

Maxwellove jednadžbe u integralnom obliku:

Gaussov zakon za \vec{E} i \vec{B} ($S = \partial V$):

$$\oint_S \vec{E} \cdot d\vec{S} = \frac{1}{\epsilon_0} \int_V \rho dV \quad \oint_S \vec{B} \cdot d\vec{S} = 0$$

Faradayev zakon indukcije ($C = \partial S$):

$$\oint_C \vec{E} \cdot d\vec{r} = -\frac{\partial}{\partial t} \int_S \vec{B} \cdot d\vec{S}$$

Ampère–Maxwellov zakon ($C = \partial S$):

$$\oint_C \vec{B} \cdot d\vec{r} = \mu_0 \int_S \vec{J} \cdot d\vec{S} + \mu_0 \epsilon_0 \frac{\partial}{\partial t} \int_S \vec{E} \cdot d\vec{S}$$

Maxwellove jednadžbe u diferencijalnom obliku:

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \quad \nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial}{\partial t} \vec{E}$$

Valna jednadžba za \vec{E} i \vec{B} :

$$\Delta \vec{E} - \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2} \vec{E} = 0 \quad \Delta \vec{B} - \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2} \vec{B} = 0$$

Ravni val, $c = 1/\sqrt{\mu_0 \epsilon_0}$, $\omega = |\vec{k}|c$:

$$\vec{E}[\vec{r}, t] = \vec{E}_0 \cos[\vec{k} \cdot \vec{r} - \omega t + \phi] \quad \vec{E}_0 \cdot \vec{k} = 0$$

$$\vec{B}[\vec{r}, t] = \vec{B}_0 \cos[\vec{k} \cdot \vec{r} - \omega t + \phi] \quad \vec{B}_0 = \hat{k} \times (\vec{E}_0/c)$$

Poyntingov vektor i gustoća energije:

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B} \quad u = \frac{1}{2} (\epsilon_0 E^2 + \frac{1}{\mu_0} B^2)$$

$$\frac{\partial}{\partial t} u + \nabla \cdot \vec{S} = -\vec{J} \cdot \vec{E}$$

Polja uz polarizaciju i magnetizaciju medija:

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P} \quad \vec{H} = \frac{1}{\mu_0} \vec{B} - \vec{M}$$

$$\vec{P} = \epsilon_0 \chi_e \vec{E} \quad \vec{D} = \epsilon \vec{E} \quad \epsilon = \epsilon_0 \epsilon_r = \epsilon_0 (1 + \chi_e)$$

$$\vec{M} = \chi_m \vec{H} \quad \vec{H} = \frac{1}{\mu} \vec{B} \quad \mu = \mu_0 \mu_r = \mu_0 (1 + \chi_m)$$

18 Fotometrija i geom. optika

Svjetlosni tok i osvijetljenost površine:

$$d\Phi = I_\Omega d\Omega \quad E = \frac{d\Phi}{dS} = \frac{I_\Omega}{r^2} \cos \beta$$

Zakon loma:

$$n = \frac{c}{v} = \sqrt{\mu_r \epsilon_r} \quad \frac{\sin \alpha}{\sin \alpha'} = \frac{n'}{n} \quad \sin \alpha_g = \frac{n'}{n}$$

Paralelni pomak Δ pri prolasku kroz planparalelnu ploču debljine d indeksa loma n' (u sredstvu n):

$$\Delta = d \sin \alpha \left(1 - \frac{\cos \alpha}{\sqrt{(n'/n)^2 - \sin^2 \alpha}} \right)$$

Kut devijacije δ pri prolasku kroz prizmu vršnog kuta A indeksa loma n' (u sredstvu n):

$$\frac{\sin \alpha_1}{\sin \alpha'_1} = \frac{n'}{n} = \frac{\sin \alpha_2}{\sin \alpha'_2} \quad \alpha'_1 + \alpha'_2 = A$$

$$\delta = (\alpha_1 - \alpha'_1) + (\alpha_2 - \alpha'_2) = \alpha_1 + \alpha_2 - A$$

minimum devijacije (pri $\alpha_1 = \alpha_2$):

$$n \sin [(\delta_{\text{min}} + A)/2] = n' \sin [A/2]$$

Sferno zrcalo:

$$\frac{1}{a} + \frac{1}{b} = \frac{2}{R} = \frac{1}{f} \quad m = -\frac{b}{a}$$

Sferni dioptrar:

$$\frac{n}{a} + \frac{n'}{b} = \frac{n' - n}{R} \quad m = -\frac{nb}{n'a}$$

Tanka leća (u sredstvu indeksa loma n):

$$\frac{1}{a} + \frac{1}{b} = \frac{n' - n}{n} \left(\frac{1}{R_1} - \frac{1}{R_2} \right) = \frac{1}{f} = J \quad m = -\frac{b}{a}$$

19 Fizikalna optika

Duljina optičkog puta svjetlosti:

$$ds = c dt = nv dt = n dr$$

Interferencija dvaju točkastih koherentnih izvora:

$$\text{konstruktivna: } \delta = s_2 - s_1 = m\lambda, \quad m = 0, \pm 1, \pm 2, \dots$$

$$\text{destruktivna: } \delta = (m + 1/2)\lambda, \quad m = 0, \pm 1, \pm 2, \dots$$

Listić debljine d u zraku, reflektirana svjetlost:

$$\text{maksimum: } 2d\sqrt{n^2 - \sin^2 \alpha} = (m + 1/2)\lambda$$

Newtonovi kolobari, $h \simeq r^2/(2R)$, reflektirana svjetlost:

$$\text{maksimum: } r = \sqrt{R(m + 1/2)\lambda}$$

$$\text{minimum: } r = \sqrt{Rm\lambda}, \quad m = 0, 1, 2, \dots$$

Dva točkasta izvora razmaknuta za d (Youngov pokus):

$$\text{maksimum: } \delta = d \sin \alpha \simeq d \frac{y}{D} = m\lambda, \quad m = 0, \pm 1, \dots$$

N točkastih izvora na međusobnom razmaku d :

$$I[\alpha] = I_0 \frac{\sin^2 \left[N \frac{\pi d}{\lambda} \sin \alpha \right]}{\sin^2 \left[\frac{\pi d}{\lambda} \sin \alpha \right]}$$

$$\text{glavni maks. } I[\alpha]: \quad \sin \alpha = \frac{\lambda}{d} m, \quad m = 0, \pm 1, \pm 2, \dots$$

$$\text{minimum } I[\alpha]: \quad \sin \alpha = \frac{\lambda}{Nd} m', \quad m' \neq mN$$

$$\text{razlučivanje: } \frac{\lambda}{\Delta \lambda} = mN, \quad \text{disperzija: } \frac{d\alpha}{d\lambda} = \frac{m}{d \cos \alpha}$$

Difrakcija na pukotini širine a :

$$I[\alpha] = I_0 \frac{\sin^2 \left[\frac{\pi a}{\lambda} \sin \alpha \right]}{\left(\frac{\pi a}{\lambda} \sin \alpha \right)^2}$$

$$\text{minimum } I[\alpha]: \quad \sin \alpha = \frac{\lambda}{a} m \quad m = \pm 1, \pm 2, \dots$$

N pukotina širine a na međusobnom razmaku d :

$$I[\alpha] = I_0 \frac{\sin^2 \left[\frac{\pi a}{\lambda} \sin \alpha \right]}{\left(\frac{\pi a}{\lambda} \sin \alpha \right)^2} \frac{\sin^2 \left[N \frac{\pi d}{\lambda} \sin \alpha \right]}{\sin^2 \left[\frac{\pi d}{\lambda} \sin \alpha \right]}$$

Polarizacija svjetlosti:

$$\text{Malusov zakon: } I[\theta] = I_0 \cos^2 \theta$$

$$\text{Brewsterov kut: } \tan \alpha_B = \frac{n'}{n}$$

20 Kvantna priroda svjetlosti

Planckova relacija:

$$E = \hbar \omega = hf = hc/\lambda$$

Zakon zračenja crnog tijela, $dP = I dS$:

$$dI = I_\lambda d\lambda \quad I_\lambda[\lambda, T] = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\exp[hc/\lambda kT] - 1}$$

$$dI = I_f df \quad I_f[f, T] = \frac{2\pi hf^3}{c^2} \frac{1}{\exp[hf/kT] - 1}$$

$$I = \int_0^\infty I_\lambda d\lambda = \int_0^\infty I_f df = \frac{2\pi^5 k^4}{15c^2 h^3} T^4 = \sigma T^4$$

$$\text{Stefan-Boltzmannov zakon: } P = S\sigma T^4$$

$$\text{Wienov zakon: } \lambda_{\max} T \simeq 2.898 \times 10^{-3} \text{ m K}$$

Fotoelektrični efekt, $E_{\text{fot.}} = \hbar \omega = hf = hc/\lambda$:

$$\frac{m_e v_e^2}{2} \leq E_{\text{fot.}} - W_{\text{izlaz}}$$

Comptonovo raspršenje, $p_{\text{fot.}} = E_{\text{fot.}}/c$:

$$hf + m_e c^2 = hf' + \gamma'_e m_e c^2 \quad \gamma'_e = 1/\sqrt{1 - (v'_e/c)^2}$$

$$\frac{hf}{c} = \frac{hf'}{c} \cos \theta'_{\text{fot.}} + \gamma'_e m_e v'_e \cos \theta'_e$$

$$0 = \frac{hf'}{c} \sin \theta'_{\text{fot.}} - \gamma'_e m_e v'_e \sin \theta'_e$$

$$\Delta \lambda = \lambda' - \lambda = \frac{c}{f'} - \frac{c}{f} = \frac{h}{m_e c} (1 - \cos \theta'_{\text{fot.}})$$

21 Struktura atoma

Bohrov model, $L_n = n\hbar = nh/(2\pi)$, $n = 1, 2, \dots$:

$$r_n = \frac{\epsilon_0 \hbar^2}{\pi m_e Z e^2} n^2 \quad E_n = -\frac{E_1}{n^2} \quad E_1 = \frac{m_e Z^2 e^4}{8\epsilon_0^2 \hbar^2}$$

$$E_{\text{fot.}} = \hbar \omega_{mn} = hf_{mn} = \frac{hc}{\lambda_{mn}} = |E_m - E_n|$$

$$\text{Vodik: } \frac{1}{\lambda_{mn}} = R_\infty \left| \frac{1}{n^2} - \frac{1}{m^2} \right| \quad R_\infty = \frac{m_e e^4}{8\epsilon_0^2 \hbar^3 c}$$

Moseleyev zakon:

$$K\text{-serija: } f = cR \left(1 - \frac{1}{n^2} \right) (Z - a)^2 \quad a \simeq 1$$

$$L\text{-serija: } f = cR \left(\frac{1}{2^2} - \frac{1}{n^2} \right) (Z - a)^2 \quad a \simeq 7.4$$

Braggov zakon:

$$2d \sin \theta = m\lambda \quad m = 1, 2, 3, \dots$$

De Broglieva relacija:

$$\lambda = \frac{h}{p} \quad p = \frac{h}{\lambda} = \hbar k = \gamma m v$$

22 Atomska jezgra

Defekt mase ($m[{}^A_ZX]$ je masa jezgre A_ZX , $m^*[{}^A_ZX]$ je masa atoma A_ZX):

$$\begin{aligned}\Delta m &= Zm_p + (A - Z)m_n - m[{}^A_ZX] \\ &= Zm^*[{}^1_1H] + (A - Z)m_n - m^*[{}^A_ZX]\end{aligned}$$

$$\text{Energija vezanja: } E_b = \Delta m c^2$$

Zakon radioaktivnog raspada i aktivnost:

$$N[t] = N[t_0]e^{-\lambda(t-t_0)} \quad A[t] = -\frac{d}{dt}N[t] = \lambda N[t]$$

$$T_{1/2} = \frac{\ln 2}{\lambda} \quad \tau = \frac{1}{\lambda}$$

Nuklearne reakcije, $a + X \rightarrow Y + b$:

$$Q = (m_X + m_a)c^2 - (m_Y + m_b)c^2$$

A Trigonometrijski identiteti

Eulerova formula ($i^2 = -1$):

$$e^{i\phi} = \cos \phi + i \sin \phi$$

Adicione formule:

$$\sin[\alpha \pm \beta] = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta$$

$$\cos[\alpha \pm \beta] = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta$$

Funkcije dvostrukog i polovice kuta:

$$\sin[2\alpha] = 2 \sin \alpha \cos \alpha$$

$$\cos[2\alpha] = \cos^2 \alpha - \sin^2 \alpha = 1 - 2 \sin^2 \alpha = 2 \cos^2 \alpha - 1$$

$$\sin \frac{\alpha}{2} = \pm \sqrt{\frac{1 - \cos \alpha}{2}} \quad \cos \frac{\alpha}{2} = \pm \sqrt{\frac{1 + \cos \alpha}{2}}$$

Kvadrat funkcije:

$$\sin^2 \alpha = (1 - \cos[2\alpha])/2 \quad \cos^2 \alpha = (1 + \cos[2\alpha])/2$$

Zbroj, razlika i produkt funkcija:

$$\sin \alpha + \sin \beta = 2 \sin[(\alpha + \beta)/2] \cos[(\alpha - \beta)/2]$$

$$\sin \alpha - \sin \beta = 2 \cos[(\alpha + \beta)/2] \sin[(\alpha - \beta)/2]$$

$$\cos \alpha + \cos \beta = 2 \cos[(\alpha + \beta)/2] \cos[(\alpha - \beta)/2]$$

$$\cos \alpha - \cos \beta = 2 \sin[(\alpha + \beta)/2] \sin[(\beta - \alpha)/2]$$

$$\sin \alpha \sin \beta = (\cos[\alpha - \beta] - \cos[\alpha + \beta]) / 2$$

$$\cos \alpha \cos \beta = (\cos[\alpha - \beta] + \cos[\alpha + \beta]) / 2$$

$$\sin \alpha \cos \beta = (\sin[\alpha - \beta] + \sin[\alpha + \beta]) / 2$$

Veza s hiperbolnim funkcijama:

$$\operatorname{sh} x = \frac{e^x - e^{-x}}{2} = -i \sin[ix] \quad i \sin x = \operatorname{sh}[ix]$$

$$\operatorname{ch} x = \frac{e^x + e^{-x}}{2} = \cos[ix] \quad \cos x = \operatorname{ch}[ix]$$

B Vektori

Vektor, modul vektora, jedinični vektor:

$$\vec{a} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k}$$

$$a = |\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad \hat{a} = \vec{a}/a$$

Skalarno množenje:

$$\vec{a} \cdot \vec{b} = ab \cos \theta = \vec{b} \cdot \vec{a} = a_x b_x + a_y b_y + a_z b_z$$

$$|\vec{a}| = \sqrt{\vec{a} \cdot \vec{a}} \quad |\vec{a} \pm \vec{b}| = \sqrt{a^2 \pm 2ab \cos \theta + b^2}$$

$$\text{komponenta } \vec{a} \text{ u smjeru } \hat{n}: \quad \vec{a}_{\parallel} = (\vec{a} \cdot \hat{n}) \hat{n}$$

$$\text{komponenta } \vec{a} \text{ okomita na } \hat{n}: \quad \vec{a}_{\perp} = \vec{a} - \vec{a}_{\parallel}$$

Vektorsko množenje:

$$\vec{a} \times \vec{b} = ab \sin \theta \hat{n} \quad (\text{smjer } \hat{n} \text{ pravilom "desne ruke"})$$

$$\vec{a} \times \vec{b} = -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

Identiteti sa skalarnim i vektorskim množenjem:

$$\vec{a} \cdot (\vec{b} \times \vec{c}) = \vec{b} \cdot (\vec{c} \times \vec{a}) = \vec{c} \cdot (\vec{a} \times \vec{b})$$

$$\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c}) \vec{b} - (\vec{a} \cdot \vec{b}) \vec{c}$$

Gradijent skalarnog polja $\phi[\vec{r}]$:

$$\nabla \phi[\vec{r}] = \frac{\partial \phi[\vec{r}]}{\partial x} \hat{i} + \frac{\partial \phi[\vec{r}]}{\partial y} \hat{j} + \frac{\partial \phi[\vec{r}]}{\partial z} \hat{k}$$

Teorem o gradijentu:

$$\int_{\vec{r}_1}^{\vec{r}_2} (\nabla \phi[\vec{r}]) \cdot d\vec{r} = \phi[\vec{r}_2] - \phi[\vec{r}_1]$$

Divergencija vektorskog polja $\vec{A}[\vec{r}]$:

$$\nabla \cdot \vec{A}[\vec{r}] = \frac{\partial A_x[\vec{r}]}{\partial x} + \frac{\partial A_y[\vec{r}]}{\partial y} + \frac{\partial A_z[\vec{r}]}{\partial z}$$

Teorem o divergenciji (Gaussov teorem):

$$\int_V (\nabla \cdot \vec{A}[\vec{r}]) dV = \oint_{S=\partial V} \vec{A}[\vec{r}] \cdot d\vec{S}$$

Rotacija vektorskog polja $\vec{A}[\vec{r}]$:

$$\nabla \times \vec{A}[\vec{r}] = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ A_x[\vec{r}] & A_y[\vec{r}] & A_z[\vec{r}] \end{vmatrix}$$

Teorem o rotaciji (Stokesov teorem):

$$\int_S (\nabla \times \vec{A}[\vec{r}]) \cdot d\vec{S} = \oint_{C=\partial S} \vec{A}[\vec{r}] \cdot d\vec{r}$$

Laplaceov operator $\Delta = \nabla \cdot \nabla$:

$$\Delta \phi[\vec{r}] = \nabla \cdot \nabla \phi[\vec{r}] = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2}$$

$$\Delta \vec{A} = \Delta A_x[\vec{r}] \hat{i} + \Delta A_y[\vec{r}] \hat{j} + \Delta A_z[\vec{r}] \hat{k}$$

Identiteti s operatorima ∇ i Δ :

$$\nabla \times \nabla \phi = 0 \quad \nabla \cdot (\nabla \times \vec{a}) = 0$$

$$\nabla \times (\nabla \times \vec{a}) = \nabla(\nabla \cdot \vec{a}) - \Delta \vec{a}$$

$$\nabla(\vec{a} \cdot \vec{b}) = (\vec{a} \cdot \nabla) \vec{b} + (\vec{b} \cdot \nabla) \vec{a} + \vec{a} \times (\nabla \times \vec{b}) + \vec{b} \times (\nabla \times \vec{a})$$

$$\nabla \times (\vec{a} \times \vec{b}) = \vec{a}(\nabla \cdot \vec{b}) - \vec{b}(\nabla \cdot \vec{a}) + (\vec{b} \cdot \nabla) \vec{a} - (\vec{a} \cdot \nabla) \vec{b}$$

$$\nabla \cdot (\vec{a} \times \vec{b}) = \vec{b} \cdot (\nabla \times \vec{a}) - \vec{a} \cdot (\nabla \times \vec{b})$$

C Fizičke konstante

Naziv:	Simbol (definicija):	Približna vrijednost:
Standardna akceleracija gravitacije	g	9.806 m s^{-2}
Gravitacijska konstanta	G_N	$6.674 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$
Brzina svjetlosti u vakuumu	c	$2.998 \times 10^8 \text{ m s}^{-1}$
Elementarni električni naboj	e	$1.602 \times 10^{-19} \text{ C}$
Permeabilnost vakuuma	$\mu_0 = 4\pi \times 10^{-7} \text{ N A}^{-2}$	$1.257 \times 10^{-6} \text{ N A}^{-2}$
Permitivnost vakuuma	$\epsilon_0 = 1/(\mu_0 c^2)$	$8.854 \times 10^{-12} \text{ F m}^{-1}$
Boltzmannova konstanta	k	$1.381 \times 10^{-23} \text{ J K}^{-1}$ $8.617 \times 10^{-5} \text{ eV K}^{-1}$
Avogadrova konstanta	$N_A = (1 \text{ g})/(u \text{ mol})$	$6.022 \times 10^{23} \text{ mol}^{-1}$
Opća plinska konstanta	$R = k N_A$	$8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
Molarni volumen (STP)	$V_0 = k N_A (273.15 \text{ K}) / (101\,325 \text{ Pa})$	$22.41 \times 10^{-3} \text{ m}^3 \text{ mol}^{-1}$
Planckova konstanta	h	$6.626 \times 10^{-34} \text{ J s}$ $4.136 \times 10^{-21} \text{ MeV s}$
Reducirana Planckova konstanta	$\hbar = h/(2\pi)$	$1.055 \times 10^{-34} \text{ J s}$ $6.582 \times 10^{-22} \text{ MeV s}$
Comptonova valna duljina elektrona	$\lambda_e = h/(m_e c)$	$2.426 \times 10^{-12} \text{ m}$
Stefan–Boltzmannova konstanta	$\sigma = 2\pi^5 k^4 / (15c^2 h^3)$	$5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Bohrov polumjer	$a_0 = r_1 = \epsilon_0 h^2 / (\pi m_e e^2)$	$5.292 \times 10^{-11} \text{ m}$
Rydbergova konstanta	$R_\infty = m_e e^4 / (8\epsilon_0^2 h^3 c)$	$1.097 \times 10^7 \text{ m}^{-1}$
Masa elektrona	m_e	$9.109\,38 \times 10^{-31} \text{ kg}$ $0.510\,999 \text{ MeV}/c^2$
Masa protona	m_p	$1.672\,62 \times 10^{-27} \text{ kg}$ $938.272 \text{ MeV}/c^2$
Masa neutrona	m_n	$1.674\,93 \times 10^{-27} \text{ kg}$ $939.566 \text{ MeV}/c^2$
Atomska jedinica mase	$u = m^* [^{12}\text{C}] / 12$	$1.660\,54 \times 10^{-27} \text{ kg}$ $931.494 \text{ MeV}/c^2$

$$T_0 = 0^\circ \text{C} = 273.15 \text{ K} \quad p_0 = 1 \text{ atm} = 101\,325 \text{ Pa} \quad 1/(4\pi\epsilon_0) = 8.988 \times 10^9 \text{ m}^2 \text{ N C}^{-2} \quad \mu_0/(4\pi) = 10^{-7} \text{ N A}^{-2}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J} \quad 1 \text{ eV}/c^2 = 1.782 \times 10^{-36} \text{ kg} \quad hc = 1240 \text{ eV nm} \quad \hbar c = 197.3 \text{ eV nm}$$