Kristali

$\alpha_{M,i} = \sum_{j\neq i} \frac{Z_j}{r_j/a}$ (Madelungova konstanta)
$V_{C,i} = \frac{e_0 \alpha_{M,i}}{4\pi\varepsilon_0 a}$
$W_{C,i} = Z_i e_0 V_{C,i}$
$V = \frac{N}{2} V_{C,i} + V_{\text{odb,k}} + \frac{N}{2} W_i - \frac{N}{2} W_a$

Blochov teorem
$\psi = e^{i\vec{k}\cdot\vec{r}} u(\vec{r})$, kjer ima $u(\vec{r})$ enako periodo kot $V(\vec{r})$, torej
$u(\vec{r}+\vec{r}_0) = u(\vec{r}) \implies \psi(\vec{r}+\vec{r}_0) = e^{i\vec{k}\cdot\vec{r}_0}\psi(\vec{r})$.

Kronig-Penny-ev model kovinske vezi

$$V(x) = \begin{cases} 0; & 0 \le x < a \\ V_0; & -b \le x < 0 \end{cases} \quad \text{in } V(x+a+b) = V(x)$$

$$\psi(x) = \begin{cases} Ae^{ikx} + Be^{-ikx}; & 0 \le x < a \\ Ce^{\kappa x} + Be^{-\kappa x}; & -b \le x < 0 \end{cases} \quad \text{in } \psi(x+a+b) = \psi(x)$$

$k = \sqrt{\frac{2mE}{\hbar^2}}$ $\qquad \kappa = \sqrt{\frac{2m(V_0-E)}{\hbar^2}}$

S približkom $b \to 0, V_0 \to \infty, P = \frac{\kappa^2 ab}{2} = konst.$ dobimo:
$P\frac{\sin(ka)}{ka} + \cos(ka) = \cos(k_l a)$
$k_l = \frac{2\pi l}{Na}, \qquad l = 1, 2, \ldots$

Valenčni pas je najvišji energijski pas v katerem so pri $T \to 0$ energijski nivoji še zasedeni z elektroni.
Prevodni pas je najnižji energijski pas v katerem so pri $T \to 0$ vsi energijski nivoji nezasedeni.
$P(\text{preskok med pasoma}) = \exp\left\{-\frac{E_g}{k_B T}\right\}$

Izolator: valenčni pas popolnoma zapolnjen, prevodni pas prazen. $E_g \sim 10$ eV.
Prevodnik: valenčni in prevodni pas sta enaka.
Polprevodnik: tudi pri nizkih T lahko elektroni preskočijo v prevodni pas. $E_g \sim 1$ eV.

Fermijeva energija
$F_{Fe}(E) = \left(\exp\left\{\frac{E-\mu}{k_B T}\right\} + 1\right)^{-1}$
$\rho_E = \frac{dg}{dE} = 4\pi(2m)^{\frac{3}{2}} \frac{V}{h^3}\sqrt{E}$
$N_{Fe} = \int_0^\infty \rho_E F_{Fe}\, dE \approx \int_0^{E_F} \rho_E\, dE$
$E_F = \mu(T\to 0) = \frac{h^2}{2m}\left(\frac{3N}{8\pi V}\right)^{\frac{2}{3}} = \frac{mv_F^2}{2}$

elektronski plin

Drudejev model prevodnosti

$p(t) = (p_0 - qE\tau)e^{-t/\tau} + eE\tau$
$j = \frac{de}{Sdt} = ne_0\langle v\rangle$
$\langle v\rangle = \frac{p(t\to\infty)}{m} = \frac{eE\tau}{m} = \beta E$
$\sigma_0 = \frac{j}{E} = \frac{ne_0^2\tau}{m}$
$\tau = \frac{a}{\langle v\rangle} \approx a\sqrt{\frac{m}{3k_BT}}$
Izmenični tok: $\sigma = \frac{\sigma_0}{\sqrt{1+\omega^2\tau^2}} e^{i\arctan(\omega\tau)}$

$\langle p\rangle = m\langle v\rangle$
$j = \sigma E$
$R = \zeta \frac{l}{S}$ $\qquad \zeta = \frac{1}{\sigma}$
$\sigma = e\beta n$ $\qquad n = \frac{N}{V}$

Efektivna masa
$m^* = \hbar^2 / \frac{d^2E}{dk^2}$
$E = \frac{p^2}{2m^*} = \frac{\hbar^2 k^2}{2m^*}$

Polprevodniki
Definiramo $E = 0$ na vrhu valenčnega pasu.

Elektroni v prevodnem pasu ($E - E_f \gg k_B T$):
$\rho_e \propto \sqrt{E - E_g}$
$F_e = e^{-(E-E_F)/k_BT}$
$n_e = \frac{N_e}{V} = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e^{-(E_g-E_F)/k_BT}$
$v_e = \beta_e E$

Vrzeli v valenčnem pasu ($E - E_f \gg k_B T$):
$\rho_v \propto \sqrt{-E}$
$F_v = 1 - F_e = e^{-(E_F-E)/k_BT}$
$n_v = \frac{N_v}{V} = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e^{-E_F/k_BT}$
$v_v = \beta_v E$
$n_e n_v \propto e^{-E_g/kT} \neq f(E_F)$
$n_e = n_v = n_0 e^{-E_g/2kT}$
Čisti polprevodnik: $n_e = n_v \implies E_F = \frac{1}{2}E_g - \frac{3}{4}k_BT\ln\frac{m_e^*}{m_v^*}$

$j = ne_0 v = j_e + j_v = \sigma E$
$\sigma = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e_0(\beta_e + \beta_v)e^{-E_g/2k_BT}$

Dopirani polprevodniki
Akceptorji imajo en elektron manj kot čisti polprevodnik.
Donorji imajo en elektron več kot čisti polprevodnik.

$n_{e_i} = n_{v_i} \implies n_e - n_D = n_v - n_A$
n-tip: $n_e \approx n_D$
p-tip: $n_v \approx n_A$

p-n stik
$$U(x) = \begin{cases} -\frac{e_0 n_D}{2\varepsilon\varepsilon_0}(x - x_n)^2 + U_0; & 0 \le x \le x_n \\ \frac{e_0 n_A}{2\varepsilon\varepsilon_0}(x + x_p)^2; & -x_p \le x \le 0 \end{cases}$$
$U_0 = \frac{e_0}{2\varepsilon\varepsilon_0}(n_D x_n^2 + n_A x_p^2)$
$x_n = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0 n_D\left(1+\frac{n_D}{n_A}\right)}\right]^{1/2}, \qquad x_p = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0 n_A\left(1+\frac{n_A}{n_D}\right)}\right]^{1/2}$
$d = x_n + x_p = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0}\frac{n_A + n_D}{n_A n_D}\right]^{1/2}$ (depletirana plast)
$U_0 = \frac{k_BT}{e_0}\ln\frac{n_e n_v}{n_{e_i} n_{v_i}}$ (kontaktna napetost)
$d \propto \sqrt{U_b + U_0} \approx \sqrt{U_b}$
$I = I_0\left(e^{e_0 U/k_bT} - 1\right)$

$C = \frac{de}{dU} = S\sqrt{\frac{\varepsilon\varepsilon_0 n_D e_0}{2(U_0+U_b)}}$ $\quad (n_a \gg n_d \implies d_n \gg d_p)$

Fotodioda
$I = I_0\left(e^{e_0 U/k_bT} - 1\right) - I_f$
$I_f = \eta 2\frac{dn_f}{dt}e_0$

$\eta = \frac{I_f \hbar c \pi}{\lambda P e_0}$

Tranzistor

$\hbar c = 197 \text{ eV nm}$
$\hbar = \frac{h}{2\pi}$

$I_c = \alpha I_e$
$I_b = (1-\alpha)I_e$
$I_b \approx I_0 e^{e_0 U_{be}/k_BT}$
$I_c = \frac{\alpha}{1-\alpha} I_0 e^{e_0 U_{be}/k_BT}$

$h = 6{,}626 \cdot 10^{-34}$ Js
$hc = 1240$ eV nm
$r_B = 5{,}291 \cdot 10^{-2}$ nm
$E_0 = 13{,}6$ eV
$\alpha_{EM} = \frac{e_0^2}{4\pi\varepsilon_0\hbar c} = \frac{1}{137}$

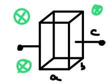
$b = 100 \text{ fm}^2$
$r_0 \approx 1{,}1$ fm
$w_0 = 15{,}6$ MeV Jedrska sila
$w_1 = 17{,}3$ MeV Površinska
$w_2 = 0{,}7$ MeV Elektrostat.
$w_3 = 23{,}3$ MeV Mešalna
$w_4 = 33{,}5$ MeV Paritvena

Jedra
Rutherfordov eksperiment: $\frac{dN}{d\Omega} \propto \sin^{-4}\frac{\vartheta}{2}$
$r_j \sin\beta = n\lambda_b$
$r_j = r_0 A^{1/3}$
$\rho_e(r) = \frac{\rho_0}{e^{(r-r_j)/s}+1}$

$M = Zm_p + Nm_n + E_v/c^2$
$E_v = -w_0 A + w_1 A^{2/3} + w_2\frac{Z^2}{A^{1/3}} + w_3\frac{(A-2Z)^2}{A} + w_4\frac{\delta_{ZN}}{A^{3/4}}$
$$\delta_{ZN} = \begin{cases} -1; & Z \text{ sod}, N \text{ sod} \\ 0; & \text{en sod en lih} \\ 1; & Z \text{ lih}, N \text{ lih} \end{cases}$$

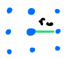
$\mu = k_D T \ln\left(\frac{n_0}{n_v}\left(\frac{m_e}{m_v}\right)^{3/4}\right)$ p-tip
$\mu = k_D T \ln\left(\frac{n_0}{n_e}\left(\frac{m_v}{m_e}\right)^{3/4}\right)$ n-tip

Hall $\quad U_H = \frac{IB}{b\cdot e\cdot n} \quad E_H = \frac{jB}{en} \quad U_H = a E_H$



Trdna snov

Madelungova konstanta (α_i)



$$W_e = -\frac{e_0^2}{4\pi\varepsilon_0 r_0}\alpha_i$$
$$W_e = W_i + W_a + W_{vez}$$

Blochov izrek
Če imam periodičen potencial, potem ψ zapišemo kot neh val krat u, u je periodičen
$$\psi(\vec r) = e^{i\vec k\vec r}\, u_k(\vec r) = \psi(\vec r + \vec R) \qquad u_k(\vec r) = u_k(\vec r + \vec R)$$

Gibljivost $\beta = \frac{e\tau}{m}$

$$\frac{d\langle\vec p\rangle}{dt} = -e\vec E - e\langle\vec v\rangle \times \vec B - \frac{\langle\vec p\rangle}{\tau}$$

$$W_F = \frac{m v_F^2}{2} = \frac{\hbar^2 k^2}{2m}$$

Sobna temperatura $k_B T = \frac{1}{40}\, eV$

Povprečna prosta pot $L = \beta v_F$

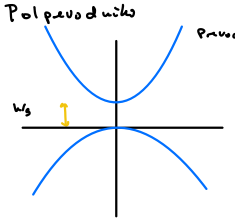
$$\omega_c = \frac{eB}{m}$$

$$\langle v\rangle = -\beta E = -\left(\frac{e\tau}{m}\right)E$$
$$j = E n \langle v\rangle$$
$$\langle p\rangle = m\langle v\rangle$$
$$j = \sigma E$$
$$R = \zeta\frac{l}{S} \qquad \zeta = \frac{1}{\sigma}$$

Spec. el. prevodnost $\sigma = e\beta n = \frac{e^2 n\tau}{m}$

$$N = 2\frac{V_F}{V_1} = 2\frac{4\pi k_F^3/3}{\left(\frac{2\pi}{L}\right)^3} = \frac{k_F^3 L^3}{3\pi^2} \qquad n = \frac{N}{L^3} = \frac{k_F^3}{3\pi^2}$$

- Polprevodniki



$$g(E) = A_e V\sqrt{E} \qquad A_e = \frac{1}{3\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\frac{3}{2}$$

$$f(E) = \frac{1}{1+\exp(\beta(E-\mu))} \qquad \beta = \frac{1}{k_B T} \qquad N = N_e + N_v$$

$$N_e = \int_{W_g}^{\infty} f(E)\, g_e(E)\, dE \qquad g(E) = \frac{g(E)}{V} = A_p\sqrt{E}$$
$$N_v = \int_{-\infty}^{0} (1-f(E))\, g_v(E)\, dE \qquad g(E) = A_v\sqrt{E}$$

$$g_p = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}\sqrt{W-W_g} = A_p\sqrt{W-W_g}$$
$$g_v = \frac{1}{2\pi^2}\left(\frac{2m_v}{\hbar^2}\right)^{3/2}\sqrt{-W} = A_v\sqrt{-W}$$
$$W = W_g + \frac{(\hbar k)^2}{2m_e}$$
$$E_F = W_g + \frac{3}{4}k_B T\ln\left(\frac{m_v}{m_e}\right)$$

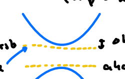
$T \to 0$
$$n_p = \frac{\sqrt\pi}{2}A_p (k_B T)^{3/2} e^{-(E_g-\mu)\beta}$$
$$n_v = \frac{\sqrt\pi}{2}A_v (k_B T)^{3/2} e^{-\mu\beta}$$

Če $n_p = n_v \Rightarrow \mu = \frac{3}{4}k_B T\ln\frac{m_v}{m_p} + \frac{E_g}{2}$

$$n_p n_v = n_0^2 e^{-\beta E_g} \qquad n_0 = \frac{1}{2\pi^2}\left(\frac{2m_v m_e}{\hbar}\right)^{3/4}\frac{\sqrt\pi}{2}\beta^{-3/2}$$

le v čistem polprev. $\rightarrow (n_p = n_v) = n_0 e^{-\beta E_g/2}$

- Dopirani polprevodniki
tip -n (5 val. e^-)

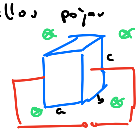


tip -p (3 val e^-)

$$\Delta E_d = \frac{e^4 m_e^*}{32\pi^2(\varepsilon\varepsilon_0)^2\hbar^2}$$ vezavna energija donorskega e^-

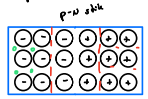
$$E_a = \frac{e^4 m_v^*}{32\pi^2(\varepsilon\varepsilon_0)^2\hbar^2}$$

- Hallov pojav

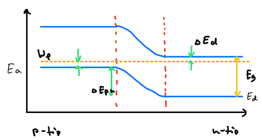


$$U_H = \frac{IB}{b\cdot e\cdot n}$$

- p-n stik



akceptor donor

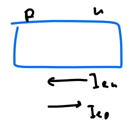


V ravnovesju sta Fermijevi en. na obeh straneh enaki
$$\Delta E_{pn} = E_{Fn} - E_{Fp} \simeq E_d - E_a$$

$$n_{ep} = \left(\frac{m_e}{m_v}\right)^{3/4} n_0\, e^{-(E_g - E_{Fn})\beta} \simeq n_d$$
$$n_v = \left(\frac{m_v}{m_e}\right)^{3/4} n_0\, e^{-E_{Fp}\beta} \simeq n_a$$
$$E_{Fn} = E_g + k_B T\left(\ln\frac{n_d}{n_0} + \frac{3}{4}\ln\frac{m_v}{m_e}\right)$$
$$E_{Fp} = -k_B T\left(\ln\frac{n_a}{n_0} + \frac{3}{4}\ln\frac{m_e}{m_v}\right)$$

- El. polje na n strani $E_n(x) = \frac{e_0 n_d}{\varepsilon\varepsilon_0}(x + d_n)$
p strani $E_p(x) = \frac{e_0 n_a}{\varepsilon\varepsilon_0}(d_p - x)$
posoj zveznosti $n_d d_n = n_a d_p$
širina plasti $\Delta E_{pn} = e_0 U_0 = \frac{e_0^2}{2\varepsilon\varepsilon_0} n_d\left(1 + \frac{n_d}{n_a}\right)d_n^2 \xrightarrow[n_d \ll n_a]{d_p \ll d_n} d_n = \sqrt{\frac{2\varepsilon\varepsilon_0 V_0}{e_0 n_d}} \approx d$

- El. tok v diodi

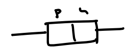


Če je še zun. napetost $d_n = \sqrt{\frac{2\varepsilon\varepsilon_0(V_0 - V)}{e_0 n_d}}$
$V > 0$ prevodna smer $d\downarrow$
$V < 0$ zaporna smer $d\uparrow$

Brez zun. napetosti
$$I_e = I_{en} - I_{ep} = 0$$
$$I_{en} = A\cdot n_0\cdot e^{-\beta(\Delta E_{pn} + E_g - E_{Fn})}$$
$$I_{ep} = A\, n_0\, e^{-\beta(E_g - E_{Fp})}$$
$$I_{vn} = A'\, n_0\, e^{-\beta(\Delta E_{pn} + E_{Fp})}$$
$$I_{vp} = A'\, n_0\, e^{-\beta E_{Fn}}$$

Zun. napetost
$$\Delta E_{pn} \rightarrow \Delta E_{pn} - e_0 U$$
$$I_e' = I_{en}\left(e^{\beta e_0 U} - 1\right)$$
$$I_v' = I_{vn}\left(e^{\beta e_0 U} - 1\right)$$
$$I' = I_0\left(e^{\beta e_0 U} - 1\right)$$

Upornik dioda



Fotodioda
$$I = I_0\left(e^{\beta e_0 U} - 1\right) - I_f$$
$$I_f = 2e_0\frac{\eta P_s}{h\nu}$$
(z notranjim uporom $V \rightarrow V_0 - IR$

Jedro

${}^{A}_{Z}X_N$ radij jedra $r_j = r_1\sqrt[3]{A_j}$ $\quad r_1 \sim 1{,}25\,\text{fm}$

$$E_v(A,Z) = -w_0 A + w_1 A^{2/3} + w_2\frac{Z^2}{A^{1/3}} + w_3\frac{(A-2Z)^2}{A} + w_4\frac{\delta_{ZN}}{A^{3/4}}$$

$$\delta_{ZN} = \begin{cases} 1 & N \text{ lih},\ Z \text{ lih} \\ 0 & N \text{ lih},\ Z \text{ sod} \\ -1 & N \text{ sod},\ Z \text{ sod} \end{cases}$$

$w_0 = 15{,}6$ MeV $\quad w_1 = 17{,}3$ MeV $\quad w_2 = 0{,}7$ MeV $\quad w_3 = 23{,}3$ MeV $\quad w_4 = 33{,}5$ MeV

Kriterij za stabilnost $E_{v,\,reakt.} \leq E_{v,\,prod.}$

s

$R = 8\,310\ \frac{\text{J}}{\text{kmol K}}$
$N_A = 6{,}02\cdot 10^{26}\ \frac{1}{\text{kmol}}$
$k_B = \frac{R}{N_A} = 1{,}38\cdot 10^{-23}\ \frac{\text{J}}{\text{K}}$

$e_0 = 1{,}602\cdot 10^{-19}$ As
$\varepsilon_0 = 8{,}85\cdot 10^{-12}\ \frac{\text{As}}{\text{Vm}}$
$\mu_0 = 4\pi\cdot 10^{-7}\ \frac{\text{Vs}}{\text{Am}}$
$c_0 = 3{,}0\cdot 10^{8}\ \frac{\text{m}}{\text{s}}$
$\sigma = 5{,}67\cdot 10^{-8}\ \frac{\text{W}}{\text{m}^2\text{K}^4}$
$k_W = 2{,}90\cdot 10^{-3}$ m · K

$u = 1{,}66\cdot 10^{-27}$ kg $= 931{,}5\ \frac{\text{MeV}}{c^2}$
$m_e = 9{,}1\cdot 10^{-31}$ kg $= 0{,}511\ \frac{\text{MeV}}{c^2}$
$m_p = 1{,}673\cdot 10^{-27}$ kg $= 938{,}3\ \frac{\text{MeV}}{c^2} = 1{,}00728u$
$m_n = 1{,}675\cdot 10^{-27}$ kg $= 939{,}6\ \frac{\text{MeV}}{c^2} = 1{,}00866u$

Kristali

$\alpha_{M,i} = \sum_{j\neq i} \frac{Z_j}{r_j/a}$ (Madelungova konstanta)
$V_{C,i} = \frac{e_0 \alpha_{M,i}}{4\pi\varepsilon_0 a}$
$W_{C,i} = Z_i e_0 V_{C,i}$
$V = \frac{N}{2} V_{C,i} + V_{\text{odb,k}} + \frac{N}{2} W_i - \frac{N}{2} W_a$

Blochov teorem
$\psi = e^{i\vec{k}\cdot\vec{r}} u(\vec{r})$, kjer ima $u(\vec{r})$ enako periodo kot $V(\vec{r})$, torej
$u(\vec{r}+\vec{r}_0) = u(\vec{r}) \implies \psi(\vec{r}+\vec{r}_0) = e^{i\vec{k}\cdot\vec{r}_0}\psi(\vec{r})$.

Kronig-Penny-ev model kovinske vezi

$$V(x) = \begin{cases} 0; & 0 \le x < a \\ V_0; & -b \le x < 0 \end{cases} \quad \text{in } V(x+a+b) = V(x)$$
$$\psi(x) = \begin{cases} Ae^{ikx} + Be^{-ikx}; & 0 \le x < a \\ Ce^{\kappa x} + Be^{-\kappa x}; & -b \le x < 0 \end{cases} \quad \text{in } \psi(x+a+b) = \psi(x)$$
$$k = \sqrt{\frac{2mE}{\hbar^2}} \qquad \kappa = \sqrt{\frac{2m(V_0-E)}{\hbar^2}}$$
S približkom $b \to 0, V_0 \to \infty, P = \frac{\kappa^2 ab}{2} = konst.$ dobimo:
$P\frac{\sin(ka)}{ka} + \cos(ka) = \cos(k_l a)$
$k_l = \frac{2\pi l}{Na}, \qquad l = 1, 2, \ldots$

Valenčni pas je najvišji energijski pas v katerem so pri $T \to 0$ energijski nivoji še zasedeni z elektroni.
Prevodni pas je najnižji energijski pas v katerem so pri $T \to 0$ vsi energijski nivoji nezasedeni.
$P(\text{preskok med pasoma}) = \exp\left\{-\frac{E_g}{k_B T}\right\}$

Izolator: valenčni pas popolnoma zapolnjen, prevodni pas prazen. $E_g \sim 10$ eV.
Prevodnik: valenčni in prevodni pas sta enaka.
Polprevodnik: tudi pri nizkih T lahko elektroni preskočijo v prevodni pas. $E_g \sim 1$ eV.

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$F_{Fe}(E) = \left(\exp\left\{\frac{E-\mu}{k_B T}\right\} + 1\right)^{-1}$
$\rho_E = \frac{dg}{dE} = 4\pi(2m)^{\frac{3}{2}} \frac{V}{h^3}\sqrt{E}$
$N_{Fe} = \int_0^\infty \rho_E F_{Fe}\, dE \approx \int_0^{E_F} \rho_E\, dE$
$E_F = \mu(T \to 0) = \frac{h^2}{2m}\left(\frac{3N}{8\pi V}\right)^{\frac{2}{3}} = \frac{mv_F^2}{2}$

elektronski plin

Drudejev model prevodnosti

$p(t) = (p_0 - qE\tau)e^{-t/\tau} + eE\tau$
$j = \frac{de}{Sdt} = ne_0\langle v\rangle$
$\langle v\rangle = \frac{p(t\to\infty)}{m} = \frac{eE\tau}{m} = \beta E$
$\sigma_0 = \frac{j}{E} = \frac{ne_0^2\tau}{m}$
$\tau = \frac{a}{\langle v\rangle} \approx a\sqrt{\frac{m}{3k_B T}}$
Izmenični tok: $\sigma = \frac{\sigma_0}{\sqrt{1+\omega^2\tau^2}} e^{i\arctan(\omega\tau)}$

$\langle p\rangle = m\langle v\rangle$
$j = \sigma E$
$R = \zeta \frac{l}{S}$ $\quad \zeta = \frac{1}{\sigma}$
$\sigma = e\beta n$ $\quad n = \frac{N}{V}$

Efektivna masa
$m^* = \hbar^2 / \frac{d^2E}{dk^2}$
$E = \frac{p^2}{2m^*} = \frac{\hbar^2 k^2}{2m^*}$

Polprevodniki

Definiramo $E = 0$ na vrhu valenčnega pasu.

Elektroni v prevodnem pasu ($E - E_f \gg k_B T$):
$\rho_e \propto \sqrt{E - E_g}$
$F_e = e^{-(E-E_F)/k_B T}$
$n_e = \frac{N_e}{V} = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e^{-(E_g-E_F)/k_B T}$
$v_e = \beta_e E$

Vrzeli v valenčnem pasu ($E - E_f \gg k_B T$):
$\rho_v \propto \sqrt{-E}$
$F_v = 1 - F_e = e^{-(E_F-E)/k_B T}$
$n_v = \frac{N_v}{V} = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e^{-E_F/k_B T}$
$v_v = \beta_v E$

$n_e n_v \propto e^{-E_g/kT} \neq f(E_F)$ $\quad \to n_e = n_v = n_0 e^{-E_g/2kT}$
Čisti polprevodnik: $n_e = n_v \implies E_F = \frac{1}{2}E_g - \frac{3}{4}k_B T \ln\frac{m_e^*}{m_v^*}$

$j = ne_0 v = j_e + j_v = \sigma E$
$\sigma = \underbrace{2\left(\frac{2\pi m^* k_B T}{h^2}\right)^{\frac{3}{2}}}_{n_0} e_0(\beta_e + \beta_v)e^{-E_g/2k_B T}$

Dopirani polprevodniki

Akceptorji imajo en elektron manj kot čisti polprevodnik.
Donorji imajo en elektron več kot čisti polprevodnik.

$n_{e_i} = n_{v_i} \quad \implies \quad n_e - n_D = n_v - n_A$
n-tip: $n_e \approx n_D$
p-tip: $n_v \approx n_A$

p-n stik
$$U(x) = \begin{cases} -\frac{e_0 n_D}{2\varepsilon\varepsilon_0}(x-x_n)^2 + U_0; & 0 \le x \le x_n \\ \frac{e_0 n_A}{2\varepsilon\varepsilon_0}(x+x_p)^2; & -x_p \le x \le 0 \end{cases}$$
$U_0 = \frac{e_0}{2\varepsilon\varepsilon_0}(n_D x_n^2 + n_A x_p^2)$
$$x_n = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0 n_D\left(1+\frac{n_D}{n_A}\right)}\right]^{1/2}, \qquad x_p = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0 n_A\left(1+\frac{n_A}{n_D}\right)}\right]^{1/2}$$
$d = x_n + x_p = \left[\frac{2\varepsilon\varepsilon_0 U_0}{e_0}\frac{n_A+n_D}{n_A n_D}\right]^{1/2}$ (depletirana plast)
$U_0 = \frac{k_B T}{e_0}\ln\frac{n_e n_v}{n_{e_i} n_{v_i}}$ (kontaktna napetost)
$d \propto \sqrt{U_b + U_0} \approx \sqrt{U_b}$
$I = I_0\left(e^{e_0 U/k_b T} - 1\right)$

$C = \frac{de}{dU} = S\sqrt{\frac{\varepsilon\varepsilon_0 n_D e_0}{2(U_0+U_b)}}$ $\quad (n_a \gg n_d \implies d_n \gg d_p)$

Fotodioda
$I = I_0\left(e^{e_0 U/k_b T} - 1\right) - I_f$
$I_f = \eta 2\frac{dn_f}{dt}e_0$ $\qquad \eta = \frac{I_f \hbar c \pi}{\lambda P e_0}$

Tranzistor
$I_c = \alpha I_e$
$I_b = (1-\alpha)I_e$
$I_b \approx I_0 e^{e_0 U_{be}/k_B T}$
$I_c = \frac{\alpha}{1-\alpha} I_0 e^{e_0 U_{be}/k_B T}$

$\hbar c = 197\,\text{eV nm}$
$\hbar = \frac{h}{2\pi}$

$h = 6{,}626 \cdot 10^{-34}$ Js
$hc = 1240$ eV nm
$r_B = 5{,}291 \cdot 10^{-2}$ nm
$E_0 = 13{,}6$ eV
$\alpha_{EM} = \frac{e_0^2}{4\pi\varepsilon_0\hbar c} = \frac{1}{137}$

$b = 100\ \text{fm}^2$
$r_0 \approx 1{,}1$ fm
$w_0 = 15{,}6$ MeV Jedrska sila
$w_1 = 17{,}3$ MeV Površinska
$w_2 = 0{,}7$ MeV Elektrostat.
$w_3 = 23{,}3$ MeV Mešalna
$w_4 = 33{,}5$ MeV Paritvena

Jedra

Rutherfordov eksperiment: $\frac{dN}{d\Omega} \propto \sin^{-4}\frac{\vartheta}{2}$
$r_j \sin\beta = n\lambda_b$
$r_j = r_0 A^{1/3}$
$\rho_e(r) = \frac{\rho_0}{e^{(r-r_j)/s}+1}$

$M = Zm_p + Nm_n + E_v/c^2$
$E_v = -w_0 A + w_1 A^{2/3} + w_2\frac{Z^2}{A^{1/3}} + w_3\frac{(A-2Z)^2}{A} + w_4\frac{\delta_{ZN}}{A^{3/4}}$
$$\delta_{ZN} = \begin{cases} -1; & Z \text{ sod}, N \text{ sod} \\ 0; & \text{en sod en lih} \\ 1; & Z \text{ lih}, N \text{ lih} \end{cases}$$

Lupinski model jedra

$\hat{H} = -\frac{\hbar^2}{2\mu}\left(\frac{\partial^2}{\partial r^2} + \frac{2}{r}\frac{\partial}{\partial r} - \frac{l(l+1)}{r^2}\right) + V(r)$
$V(r) = -V_0/\left[e^{(r-r_j)/s} + 1\right]$ (Saxon-Woodsov potencial)
$\hat{H}_{ls} = -\eta\,\hat{\vec{l}}\cdot\hat{\vec{s}}$

Nukleona imata $s = \frac{1}{2}$.
Lupine pri Saxon-Woodsu z dovolj veliko η (nl_j):
1. $1s_{1/2} \implies$ magično število 2
2. $1p_{3/2}$, $1p_{1/2} \implies$ magično število 8
3. $1d_{5/2}$, $2s_{1/2}$, $1d_{3/2} \implies$ magično število 20
4. $1f_{7/2} \implies$ magično število 28
5. $2p_{3/2}$, $1f_{5/2}$, $1p_{1/2}$, $1g_{9/2} \implies$ magično število 50
6. $1g_{7/2}$, $2d_{5/2}$, $1d_{3/2}$, $3s_{1/2}$, $1h_{11/2} \implies$ magično število 82
7. $1h_{9/2}$, $2f_{7/2}$, $2f_{5/2}$, $3p_{3/2}$, $3p_{1/2}$, $1i_{13/2} \implies$ mš 126

Spin sodo-lihega (oz. liho-sodega) jedra je enak celotni vrtilni količini zadnjega neparnega nukleona.
Spin sodo-sodega jedra je 0.
Spin liho-lihega jedra ne moremo natančno določiti, možne so vse kombinacije VK zadnjih dveh nukleonov.

Parnost sodo-lihega (oz. liho-sodega) jedra je $(-1)^l$, kjer l pripada zadnjemu neparnemu nukleonu.
Parnost sodo-sodega jedra je $+$.
Parnost liho-lihega jedra je $(-1)^{l_p}(-1)^{l_n}$, kjer l_p, l_n pripadata zadnjima nukleonoma.

Jedrski razpadi in prehodi s sevanjem

$\frac{dN}{N} = -\lambda dt = -\frac{dt}{\tau} = -\ln 2\frac{dt}{t_{1/2}}$
$A = |\frac{dN}{dt}| = \lambda N$
$\frac{dN}{dt} = \sum_i \pm_i \lambda_i N_i$

Sevanje γ
$\frac{1}{\tau} = \frac{\omega_{12}^3|\vec{p}_{12}|^2}{3\pi\varepsilon_0 c^3\hbar}$
$\omega_{12} = \frac{E_{12}}{\hbar}$

$\vec{p}_{12} = \int R_1^*(\vec{r})\vec{p}R_2(\vec{r})d^3r$ $\Delta L = \pm 1$ L, S
$\delta E\ \tau \approx \hbar$ $\Delta M_l = \pm 1, 0$
$\Delta J = 0, \pm 1, \quad \Delta M_J = 0, \pm 1,$ parnost se mora spremeniti
Prehod iz $J = 0$ v $J' = 0$ ni mogoč.
Obstajajo tudi električni in magnetni multipolni prehodi.
$E_\gamma^{\text{emis}} = E_{12}\left(1 - \frac{E_{12}}{2m_jc^2}\right), \qquad E_\gamma^{\text{abs}} = E_{12}\left(1 + \frac{E_{12}}{2m_jc^2}\right)$

Razpad α
${}^A_Z\text{X}_N \to {}^{A-4}_{Z-2}\text{Y}_{N-2} + {}^4_2\text{He}_2$
$Q = (M_Y + M_\alpha - M_X)c^2 < 0$
$T_\alpha = \frac{-Q}{1+m_\alpha/m_Y}$

Razpad β^-
${}^A_Z\text{X}_N \to {}^{A}_{Z+1}\text{Y}_{N-1} + e^- + \overline{\nu}_e$
$Q = (M_Y + M_e - M_X)c^2 < 0$
$T_e^{\max} = \frac{-Q}{1+m_e/m_Y} \approx -Q$

Razpad β^+
${}^A_Z\text{X}_N \to {}^{A}_{Z-1}\text{Y}_{N+1} + e^+ + \nu_e$

Jedrske reakcije

št. interakcij   št. vpadnih delcev   št. delcev v tarči

$\sigma = \frac{N_rS}{N_vN_j} = \frac{N_r}{j_vtN_j}$ (sipalni presek) $N_r = N : N_j \frac{\sigma}{S}$
$\sigma_r = \sum_\rho \sigma_{r_\rho}$
$\frac{d\sigma}{d\Omega} = \frac{1}{j_vtN_j}\frac{dN_r(\vartheta)}{d\Omega} = \frac{b}{\sin\vartheta}\left|\frac{db}{d\vartheta}\right|$ (diferencialni sipalni presek)
$P_r = \frac{N_r}{N_v} = n_j\sigma l$

Coulombsko sipanje: $\frac{d\sigma}{d\cos\vartheta} = 2\pi\left(\frac{Z_1Z_2e_0^2}{16\pi\varepsilon_0T}\right)^2\frac{1}{\sin^4(\vartheta/2)}$

Delci

Vsi delci imajo svoje antidelce z enako maso in spinom ter nasprotnimi ostalimi kvantnimi števili.

Leptoni

delec	masa	naboj $[e_0]$	spin	generacija
elektron e	0,511 MeV/c^2	-1	$\frac{1}{2}$	1.
mion μ	105 MeV/c^2	-1	$\frac{1}{2}$	2.
tao τ	1,78 GeV/c^2	-1	$\frac{1}{2}$	3.
ν_e	~ 0	0	$\frac{1}{2}$	1.
ν_μ	~ 0	0	$\frac{1}{2}$	2.
ν_τ	~ 0	0	$\frac{1}{2}$	3.

Kvarki

okus	masa	naboj $[e_0]$	spin	generacija
up	2.2 MeV/c^2	$\frac{2}{3}$	$\frac{1}{2}$	1., zgornji
down	4.7 MeV/c^2	$-\frac{1}{3}$	$\frac{1}{2}$	1., spodnji
charm	1.3 GeV/c^2	$\frac{2}{3}$	$\frac{1}{2}$	2., zgornji
strange	96 MeV/c^2	$-\frac{1}{3}$	$\frac{1}{2}$	2., spodnji
top	170 GeV/c^2	$\frac{2}{3}$	$\frac{1}{2}$	3., zgornji
bottom	4.2 GeV/c^2	$-\frac{1}{3}$	$\frac{1}{2}$	3., spodnji

Izospin: $i(u,d) = \frac{1}{2}, i_3(u) = \frac{1}{2}$, $i_3(d) = -\frac{1}{2}$, za ostale $i = i_3 = 0$.
Barionsko število: $B = \frac{1}{3}$ za vse kvarke.
Čudnost: $S(s) = -1$, za ostale $S = 0$.
Čar: $C(c) = 1$, za ostale $C = 0$.
Dno: $\mathcal{B}(b) = -1$, za ostale $\mathcal{B} = 0$.
Vrh: $T(t) = 1$, za ostale $T = 0$.
Barva: R, G ali B, vsi kvarki lahko imajo poljubno.

$Y = S + C + \mathcal{B} + T + B$ (hipernaboj)
$\frac{e}{e_0} = i_3 + \frac{1}{2}Y$

Hadroni

Barioni so sestavljeni iz 3 kvarkov ali 3 antikvarkov, ki imajo različno barvo.
Mezoni so sestavljeni iz kvarka in antikvarka s konjugirano enako barvo.

Posredniki interakcij

delec	masa	naboj $[e_0]$	spin
gluon	0	0	1
foton γ	0	0	1
Z	91.2 GeV/c^2	0	1
W	80.4 GeV/c^2	± 1	1
H	125 GeV/c^2	0	0

Gluonov je 8 vrst, vsi nosijo en barvni in en antibarvni naboj.

Interakcije

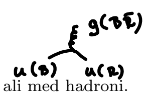
Posredujejo jih virtualni delci, ki lahko obstajajo le v skladu s Heisenebergovim načelom $\Delta E\Delta t \geq \hbar$.
Velikostni red dosega: $\lambda_C = \frac{\hbar c}{mc^2}$

$M_{i\to f} = \langle f|\,H_{\text{int}}\,|i\rangle = \prod_{\text{verteks}}|M|$ (matrični element)
Fermijevo zlato pravilo: $\Gamma_{i\to f} = \frac{2\pi}{\hbar}|M_{i\to f}|^2\rho(E) \propto |M_{i\to f}|^2$
(razpadna širina - verjetnost za razpad na časovno enoto)
$\tau_{i\to f} = \frac{1}{\Gamma_{i\to f}}$ razpadna širina
$\Gamma_i^{\text{tot}} = \sum_f \Gamma_{i\to f}$
$\text{Br}(i \to f) = \frac{\Gamma_{i\to f}}{\Gamma_i^{\text{tot}}}$ (razvejitveno razmerje)
$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2}\frac{|M_{i\to f}|^2}{E_{\text{CM}}^2}\frac{|\vec{p}_f|}{|\vec{p}_i|} \propto |M_{i\to f}|^2$

Elektromagnetna interakcija e^+e^-, $q\bar{q}$, sipanje e^-e^- qq

Deluje med nabitimi leptoni ali nabitimi kvarki.
Posrednik foton.
$|M| \propto e \propto \sqrt{\alpha_{EM}}$

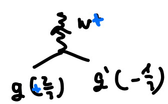
Močna interakcija

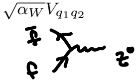


Deluje med kvarkom in antikvarkom ali med hadroni.
Posredniki gluoni (med kvarki) in mezoni (med npr. nukleoni).
$|M| \propto \sqrt{\alpha_S}$
Približek Yukawin potencial (med q, $\bar{q}$): $V(r) = -V_0\frac{r_0}{r}e^{-r/r_0}$

Šibka interakcija

Nabita deluje med leptonom in pripadajočim nevtrinom ali med kvarkoma.
Nevtralna deluje med dvema fermionoma.
Posrednika Z in $W^\pm$.
$|M| \propto \sqrt{\alpha_W}$
$|M_{q_1q_2}| \propto \sqrt{\alpha_W}V_{q_1q_2}$





$V_{\text{CKM}} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$

Ohranitveni zakoni

$p^\mu = (E/c, \vec{p}) = konst.$ (invarianta $p^\mu p_\mu$)
Naboj se ohranja pri vseh interakcijah.
Barionsko število se ohranja pri vseh interakcijah.
Leptonsko število se ohranja po generacijah pri vseh interakcijah.
Okus kvarka se ohranja pri vseh interakcijah, razen pri nabiti šibki interakciji.

Operator parnosti: $\hat{P}\psi(\vec{r}) = \psi(-\vec{r})$, lastne vr. $P = \pm 1$.
Operator konjugacije naboja: $\hat{C}\psi = \overline{\psi}$, lastne vr. $C = \pm 1$.
Operator sučnosti: $\hat{\Sigma} = \hat{\vec{S}}\frac{\hat{\vec{p}}}{\hat{p}}$, lastne vr. $\Sigma = \pm\frac{1}{2}$.

Šibka interakcija krši ohranitev parnosti $\hat{P}$ in konjugirane parnosti $\hat{C}\hat{P}$. Nabojna parnost

Fizikalne konstante

$R = 8\ 310\ \frac{\text{J}}{\text{kmol K}}$
$N_A = 6{,}02 \cdot 10^{26}\ \frac{1}{\text{kmol}}$
$k_B = \frac{R}{N_A} = 1{,}38 \cdot 10^{-23}\ \frac{\text{J}}{\text{K}}$

$e_0 = 1{,}602 \cdot 10^{-19}$ As
$\varepsilon_0 = 8{,}85 \cdot 10^{-12}\ \frac{\text{As}}{\text{Vm}}$
$\mu_0 = 4\pi \cdot 10^{-7}\ \frac{\text{Vs}}{\text{Am}}$
$c_0 = 3{,}0 \cdot 10^8\ \frac{\text{m}}{\text{s}}$
$\sigma = 5{,}67 \cdot 10^{-8}\ \frac{\text{W}}{\text{m}^2\text{K}^4}$
$k_W = 2{,}90 \cdot 10^{-3}$ m · K

$u = 1{,}66 \cdot 10^{-27}$ kg $= 931{,}5\ \frac{\text{MeV}}{\text{c}^2}$
$m_e = 9{,}1 \cdot 10^{-31}$ kg $= 0{,}511\ \frac{\text{MeV}}{\text{c}^2}$
$m_p = 1{,}673 \cdot 10^{-27}$ kg $= 938{,}3\ \frac{\text{MeV}}{\text{c}^2} = 1{,}00728u$
$m_n = 1{,}675 \cdot 10^{-27}$ kg $= 939{,}6\ \frac{\text{MeV}}{\text{c}^2} = 1{,}00866u$

$h = 6{,}626 \cdot 10^{-34}$ Js
$hc = 1240$ eV nm
$r_B = 5{,}291 \cdot 10^{-2}$ nm
$E_0 = 13{,}6$ eV
$\alpha_{EM} = \frac{e_0^2}{4\pi\varepsilon_0\hbar c} = \frac{1}{137}$

$b = 100$ fm^2
$r_0 \approx 1{,}1$ fm
$w_0 = 15{,}6$ MeV
$w_1 = 17{,}3$ MeV
$w_2 = 0{,}7$ MeV
$w_3 = 23{,}3$ MeV
$w_4 = 33{,}5$ MeV

$|V_{\text{CKM}}| = \begin{bmatrix} 0{,}97428 & 0{,}2253 & 0{,}00347 \\ 0{,}2252 & 0{,}97345 & 0{,}0410 \\ 0{,}00862 & 0{,}0403 & 0{,}999152 \end{bmatrix}$

Lupinski model jedra

$\hat{H} = -\frac{\hbar^2}{2\mu}\left(\frac{\partial^2}{\partial r^2} + \frac{2}{r}\frac{\partial}{\partial r} - \frac{l(l+1)}{r^2}\right) + V(r)$

$V(r) = -V_0/\left[e^{(r-r_j)/s} + 1\right]$ (Saxon-Woodsov potencial)

$\hat{H}_{ls} = -\eta\,\hat{\vec{l}}\cdot\hat{\vec{s}}$

$s = 0{,}55\,\mathrm{fm}$ $\quad V_0 = 50\,\mathrm{MeV}$ $\quad r_j = r_0\sqrt[3]{A}$ $\quad \eta = 20\,A^{-2/3}\,\frac{\mathrm{MeV}}{\hbar^2}$

Nukleona imata $s = \frac{1}{2}$.

Lupine pri Saxon-Woodsu z dovolj veliko η (nl_j):

$\dots, 2, 1 = n$ $\quad l = 0, 1, 2, 3$ $\quad 1s_{1/2}$ $\quad j = |l \pm \frac{1}{2}|$

1. $1s_{1/2}$ $\implies$ magično število 2
2. $1p_{3/2}$, $1p_{1/2}$ $\implies$ magično število 8
3. $1d_{5/2}$, $2s_{1/2}$, $1d_{3/2}$ $\implies$ magično število 20
4. $1f_{7/2}$ $\implies$ magično število 28
5. $2p_{3/2}$, $1f_{5/2}$, $1p_{1/2}$, $1g_{9/2}$ $\implies$ magično število 50
6. $1g_{7/2}$, $2d_{5/2}$, $1d_{3/2}$, $3s_{1/2}$, $1h_{11/2}$ $\implies$ magično število 82
7. $1h_{9/2}$, $2f_{7/2}$, $2f_{5/2}$, $3p_{3/2}$, $3p_{1/2}$, $1i_{13/2}$ $\implies$ mš 126

Močno vezane stanje so tam kjer je št. p^+ in/ali n^0 magično.

Spin sodo-lihega (oz. liho-sodega) jedra je enak celotni vrtilni količini zadnjega neparnega nukleona. $= j$

Spin sodo-sodega jedra je 0.

Spin liho-lihega jedra ne moremo natančno določiti, možne so vse kombinacije VK zadnjih dveh nukleonov.

Parnost sodo-lihega (oz. liho-sodega) jedra je $(-1)^l$, kjer l pripada zadnjemu neparnemu nukleonu.

Parnost sodo-sodega jedra je $+1$

Parnost liho-lihega jedra je $(-1)^{l_p}(-1)^{l_n}$, kjer l_p, l_n pripadata zadnjima nukleonoma.

Coulombovo sipanje

$\sigma(\theta_1 < \theta < \theta_2) = \left(\frac{e_1 e_2}{16\pi\varepsilon_0 T}\right)^2 8\pi\left(\frac{1}{1-\cos\theta_1} - \frac{1}{1-\cos\theta_2}\right)$

$M = Zm_p + Nm_n + E_v/c^2$

$E_v = -w_0 A + w_1 A^{2/3} + w_2\frac{Z^2}{A^{1/3}} + w_3\frac{(A-2Z)^2}{A} + w_4\frac{\delta_{ZN}}{A^{3/4}}$

$\delta_{ZN} = \begin{cases} -1; & Z \text{ sod}, N \text{ sod} \\ 0; & \text{en sod en lih} \\ 1; & Z \text{ lih}, N \text{ lih} \end{cases}$

Jedrski razpadi in prehodi s sevanjem

${}^A_Z X \to {}^4_2\alpha + {}^{A-4}_{Z-2}Y$

$\frac{dN}{N} = -\lambda dt = -\frac{dt}{\tau} = -\ln 2\frac{dt}{t_{1/2}}$

$A = |\frac{dN}{dt}| = \lambda N$

$\frac{dN}{dt} = \sum_i \pm_i \lambda_i N_i$

$\tau = \frac{t_{1/2}}{\ln 2}$

Geiger Nuttalova en.

$\ln\tau = \frac{a'}{\sqrt{T}} - b'$ $\quad$ kin. en. α delca $\quad a' = \frac{e_0^2 (Z-2)\sqrt{2m_r}}{2\varepsilon_0\hbar}$

$\frac{1}{m_r} = \frac{1}{m_\alpha} + \frac{1}{m_Y}$ $\quad R = r_\alpha + r_Y$ $\quad r_\alpha = r_0 A_\alpha^{1/3}$

$b' = \frac{4e_0}{\hbar}\left(\frac{(Z-2)m_r R}{\pi\varepsilon_0}\right)^{1/2} + \ln\sqrt{\frac{T}{2m_r R^2}}$

Sevanje γ

$\frac{1}{\tau} = \frac{\omega_{12}^3|\vec{p}_{12}|^2}{3\pi\varepsilon_0 c^3\hbar}$

$\omega_{12} = \frac{E_{12}}{\hbar}$

Rutherfordovo sipanje

$V = -\frac{\alpha}{r}$ $\quad \alpha = \frac{e_1 e_2}{4\pi\varepsilon_0}$

$b = \frac{\alpha}{2E}\cot\frac{\theta}{2}$ $\quad E = \frac{m v_0^2}{2}$

$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha}{4E}\right)^2\frac{1}{\sin^4\theta/2}$

$\frac{e_0^2}{4\pi\varepsilon_0\hbar c} = \alpha = \frac{1}{137}$

Dopplerjev efekt

- izvor mir. spr. prem.

$\nu' = \nu\left(1 \pm \frac{v}{c}\right)$

približevanje $\quad$ oddaljevanje

- izvor premik., spr. mir

$\nu' = \nu / \left(1 \pm \frac{v}{c}\right)$

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

Gibalna količina delca

$\vec{p} = \gamma_v m_0 \vec{v}$ $\quad$ glede na mirovanje

mirovna masa

Energije

$T = m_0 c^2(\gamma - 1)$

$E_0 = m_0 c^2$

$E = E_0 + T = \gamma m_0 c^2$

$E^2 = m^2c^4 + p^2c^2$

$pc = \gamma\beta m c^2 = \beta E$

$pc = \sqrt{T(T + 2mc^2)}$

$\hbar c = 200\,\mathrm{eV\,nm}$

$hc = 1240\,\mathrm{eV\,nm}$

$m_e c^2 = 511\,\mathrm{keV}$

barvno nevtralni

Hadroni

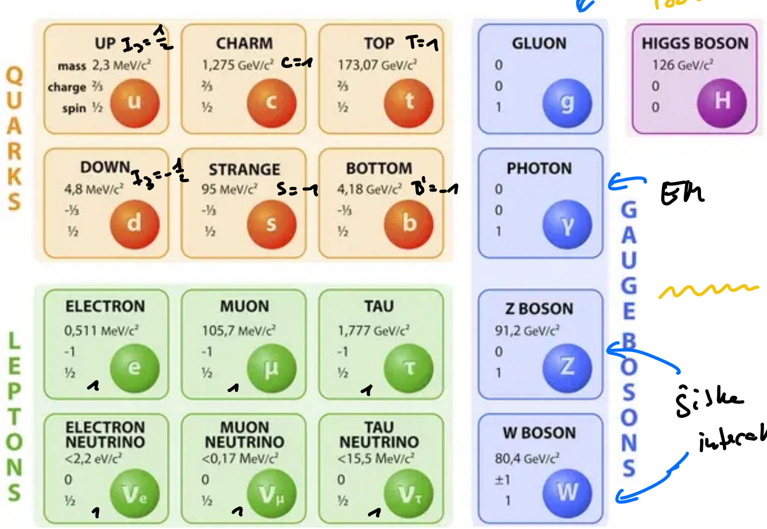
Barioni qqq

Mezoni $q\bar{q}$

Fermioni

Bozoni

močne interakcije



EM

šibke interakcije

Leptonska števila L_e L_μ L_τ

Leptonsko št. se VEDNO ohranja.