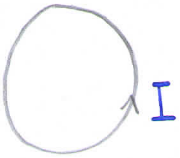
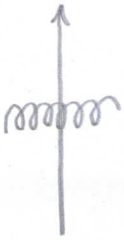
Magnetni moment



$S = \pi r^2$

$\boxed{\vec{p}_M = \vec{S} I}$ klasična fizika

(v kv. mehaniki oznaka $\vec{\mu}$



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

$$\mu = S \cdot I = S \cdot \frac{\Delta e}{\Delta t} = \pi r^2 \frac{e}{t_0} = \frac{\pi r r e 2}{t_0 \cdot 2} = \frac{r v e}{2}$$

obhodna hitrost

$\boxed{e = -e_0}$

$L = m r v$

$r v = \frac{L}{m} \Rightarrow$ $\boxed{\mu = \frac{-L e_0}{2m}}$ $\vec{\mu} = -\frac{e_0}{2m}\vec{L}$

W_M (magnetna energija) $= -\vec{\mu} \cdot \vec{B} = -\mu_z \cdot B =$

$$\boxed{W_M = -\mu \cdot B \cdot \cos\varphi}$$

$\vec{B} = (0, 0, B)$
v smeri z

$\vec{F}_M = -\vec{\nabla} W_M$: B - homogeno

$\vec{F}_M = -\mu_z \vec{\nabla} B$ $\frac{\partial B}{\partial z} = 0$, $\frac{\partial B}{\partial x} = \frac{\partial B}{\partial y} = 0 \Rightarrow \boxed{\vec{F}_M = 0}$

v homogenem mag. polju

KVANTNI SVET:

$$\hat{\vec{\mu}} = -\frac{e_0}{2m}\hat{\vec{L}}$$

$$|\hat{\vec{\mu}}| = \frac{e_0}{2m}\sqrt{l(l+1)}\,\hbar = \frac{e_0 \hbar}{2m}\sqrt{l(l+1)} =$$

$$\boxed{\mu_B = 9{,}247 \cdot 10^{-24} \frac{J}{T}}$$

Bohrov magneton

$$\boxed{|\hat{\vec{\mu}}| = \mu_B \sqrt{l(l+1)}}$$

vodikov atom v hom. mag. polju:

$$\hat{H} = -\frac{\hbar^2}{2m}\vec{\nabla}^2 - \frac{e_0^2}{4\pi\varepsilon_0 r} - \hat{\mu}_z B$$

$$\hat{H} = \underline{\hat{H}_0} + \frac{e_0}{2m} B \hat{L}_z$$

Ham. operator za prost H atom

$$H_0 \Psi_{nlm} = E_n \Psi_{nlm}$$

$$[\hat{L}_z, \hat{H}_0] = 0$$

$$\underline{[\hat{H}, \hat{H}_0]} = [\hat{H}_0 + \frac{e_0}{2m} B \hat{L}_z, \hat{H}_0] =$$

$$= \underbrace{[\hat{H}_0, \hat{H}_0]}_{0} + \frac{e_0}{2m} B \underbrace{[\hat{L}_z, \hat{H}_0]}_{0} = \underline{\underline{0}}$$

komutirata => enake lastne funkcije

$$\hat{H}\Psi_{nlm} = \hat{H}_0 \Psi_{nlm} + \frac{e_0}{2m} B \hat{L}_z \Psi_{nlm} =$$

$$= E_n \Psi_{nlm} + \frac{e_0 B}{2m} \underline{m\hbar} \Psi_{nlm} =$$

iz $\hat{L}_z \Psi_{nlm} = m\hbar \Psi_{nlm}$

$$\boxed{\hat{H}\Psi_{nlm} = (E_n + \mu_B B m)\Psi_{nlm}}$$

$B = 0$	$B \neq 0$
H atom: $E_n \to n^2$ $n = 1, 2, 3 \ldots$ $n \geq l + 1$ za l $-l \leq m \leq l$	nivo se razcepi na $(2l+1)$ nivojev

$n = 1$ 1 nivo

$n = 2$ 4 nivoji:

n	l	m
2	0	0
2	1	1
2	1	1
2	1	-1

ista energija $E_n = \frac{-13{,}6\,\text{eV}}{4}$

⇙

200, 210 $\}$ $\Delta E = 0$

211 $\Delta E = \mu_B B \; (m = 1)$

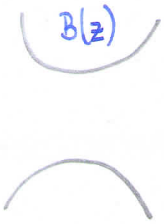
21-1 $\Delta E = -\mu_B B \; (m = -1)$

$\}$ $(2l+1)$ nivojev

$B = 1T$:

$\Delta E = \mu_B B = 5{,}8 \cdot 10^{-5}\, eV$ → vzrok za več spektralnih črt; črte pri eni valovni dolžini, ne samo ena

H atom →



nehomogeno mag. polje

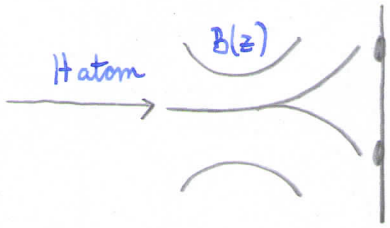
$\vec{F} = -\vec{\mu}\nabla\vec{B}$

$F_{Mz} = \mu_z \frac{\partial B}{\partial z} = m\hbar \frac{\partial B}{\partial z}$

sklepamo, da H atom prečka nehom. mag. polje brez spremembe ⇒ naj bi videli eno piko

⇓

TO NI RES:



2 piki

Stern - Gerlach: 2 piki

$2l + 1 = 2$ iz meritev Ag atoma

$l = \frac{1}{2}$??

elektron ima 2 vrtilni količini: okoli jedra + okoli lastne osi

Uvedemo SPIN:

$\boxed{\hat{\vec{S}} = (\hat{S}_x, \hat{S}_y, \hat{S}_z)}$; $\hat{S}^2 = \hat{S}_x^2 + \hat{S}_y^2 + \hat{S}_z^2$

$[\hat{S}_x, \hat{S}_y] = i\hbar\hat{S}_z$

⇓

$[\hat{S}_x, \hat{S}^2] = 0$

$[\hat{S}_y, \hat{S}^2] = 0$

$[\hat{S}_z, \hat{S}^2] = 0$

$\langle \hat{L}^2 \rangle = l(l+1)\hbar^2$

$\langle \hat{S}^2 \rangle = s(s+1)\hbar^2$

$s = \frac{1}{2}$, saj $\langle S^2 \rangle = \frac{3}{4}\hbar^2$

$\langle \hat{L}_z \rangle = m\hbar$ $\quad -l \le m \le l$

$\langle \hat{S}_z \rangle = m_s\hbar$

$-s \le m_s \le s$

$\boxed{-\frac{1}{2}, \frac{1}{2}}$

imamo 2 stanji:

$\langle \hat{S}_z \rangle = -\frac{1}{2}\hbar \quad |\downarrow\rangle \quad \beta$

$\langle \hat{S}_z \rangle = \frac{1}{2}\hbar \quad |\uparrow\rangle \quad \alpha$

Jo lahko izračunamo po relativističnih kv. pojemih; v klasični kv. mehaniki naredimo poizkus

Torej imamo 5 kv. števil:

$\boxed{n \quad l \quad m \quad s \quad m_s}$ } govorimo lahko le o 4 kv. št., saj je s velikost m_s-ja in je vedno $\frac{1}{2}$

$s = \frac{1}{2}$

$\psi = \psi_{nlm\alpha}$, $\psi_{nlm\beta}$ } osnovno stanje

$n = 1$

$l = 0$ $\Rightarrow$ degeneracija $\boxed{2n^2}$

$m = 0$

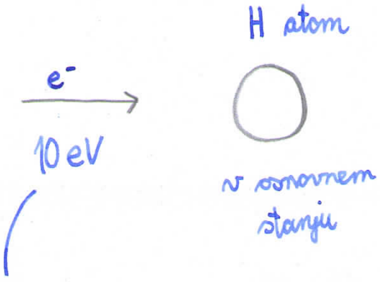
$m_s = \pm\frac{1}{2}$

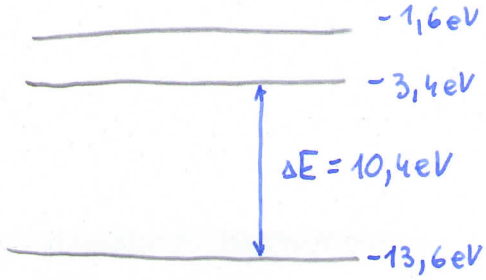
$\vec{\mu} = \cancel{\hat{l}} + \_\vec{s} \sim \boxed{F_M \propto S_z \frac{\partial B}{\partial z}}$

$[\hat{S}^2, \hat{H}] = 0$

$[\hat{S}_z, \hat{H}] = 0$ } do $M_r = 40$; $M_r > 40$ upoštevamo relativistično kv. mehaniko

Prehodi med stanji





samo prožni trki, saj energija 10eV ne ustreza potrebni energiji za vzbujenost e^- v H atomu

Potrebujemo energijo $>10,2\,eV = \Delta E$!!!

$$\boxed{\begin{aligned} \vec{G}_z &= \vec{G}_k \\ W_z &= W_k \end{aligned}}$$

Termična energija:

$$W_T = \frac{3}{2} kT \quad (T = 25°C) = \frac{3}{2} \cdot 1{,}38 \cdot 10^{-23} \frac{J}{K} \cdot 298\,K =$$

samo prožni trki $\quad = \underline{0{,}025\,eV}$.

Za H_2: ~2000K razpad molekul na atome
~3000K vzbujanje e^- na osn. njih } primer neonk (plini, ki jih s termično E vzbudimo)

SPONTANA EMISIJA:

atom

$$u \longrightarrow g$$

$$e^{-\frac{t}{\tau}} \quad \Big\} \quad \frac{1}{\tau} = \frac{\omega_{gu}^3 \mu e_{gu}^2}{3\pi \varepsilon_0 c^3 \hbar}$$

krožna frekvenca

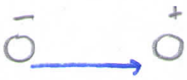
električni dipolni moment prehoda

tau

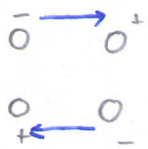
po kolikšnem času bomo imeli $\frac{1}{2}$ vseh atomov v vzbujenem stanju

$$\omega_{gu} = \frac{W_u - W_g}{\hbar}$$

$$\boxed{\tau = \frac{3\pi\varepsilon_0 c^3 \hbar}{\omega_{gu}^3 \mu e_{gu}^2}}$$



$$\boxed{\vec{\mu}_e = e\vec{r}}$$



Poznamo el. in mag. dipole,
KVADROPOLE,
OKTAPOLE. | ni potrebno znati.

$\rho = |\psi|^2$ gostota e^-

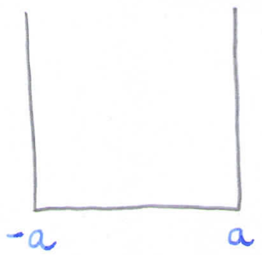
$$\vec{\mu}_e = \langle \hat{\vec{r}} \rangle = \int \vec{r} \rho \, dV = \int \vec{r} \psi \psi^* dV$$

– številčna gostota; pomnožimo z $-e_0$: $\boxed{\vec{\mu}_e = -e_0 \int \vec{r} \psi \psi^* dV}$ el. dipol

$$\vec{\mu}_e = -e_0 \int \Psi_n^* \vec{r}\, \Psi_n \, dV$$

$$\boxed{\vec{\mu}_{e_{gu}} = -e_0 \int \Psi_g^* \vec{r}\, \Psi_u \, dV}$$ dipolni moment prehoda

Uglejmo si neskončno potencialno jamo :



$$E_n = \frac{h^2 n^2}{32 m a^2}$$

$$\Psi_n = \sqrt{\frac{1}{a}} \cos\frac{n\pi x}{2a} \Big\}\ \text{za lihe } n$$

$$\Psi_n = \sqrt{\frac{1}{a}} \sin\frac{n\pi x}{2a} \Big\}\ \text{za sode } n$$

prehod na isto stanje:

$\overline{|n \rightarrow n|}$

$$\mu_{e_{nn}} = -e_0 \int_{-a}^{a} \Psi_n^* x \Psi_n dx = -e_0 \int_{-a}^{a} \underbrace{x \Psi_n^2}_{\text{liha funkcija}} dx = \underline{\underline{0}}$$

prehod sodih stanj :

$\overline{|m \rightarrow n|}$

$$\mu_{e_{mn}} = -e_0 \int_{-a}^{a} \underbrace{\Psi_m x \Psi_n}_{\text{liha funkcija}} dx = \underline{\underline{0}}$$

prehod lihih stanj :

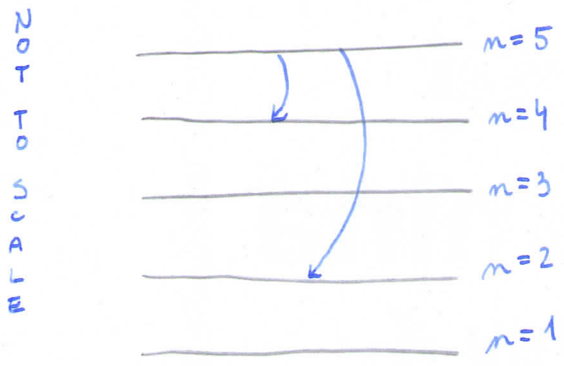
$\overline{|m \rightarrow n|}$

$$\mu_{e_{mn}} = -e_0 \int_{-a}^{a} \underbrace{\Psi_m x \Psi_n}_{\text{liha funkcija}} dx = \underline{\underline{0}}$$

prehod s sodega na liho stanje in obratno :

$\boxed{m \to n}$

$$\mu_{e\,mn} = -e \int_{-a}^{a} \underbrace{\psi_m x \psi_n \, dx}_{\text{soda funkcija}} \neq 0$$



Krivec prehodov je **NIHANJE EL. DIPOLA** !

---

harmonski oscilator :

$$|n-m| = 1$$

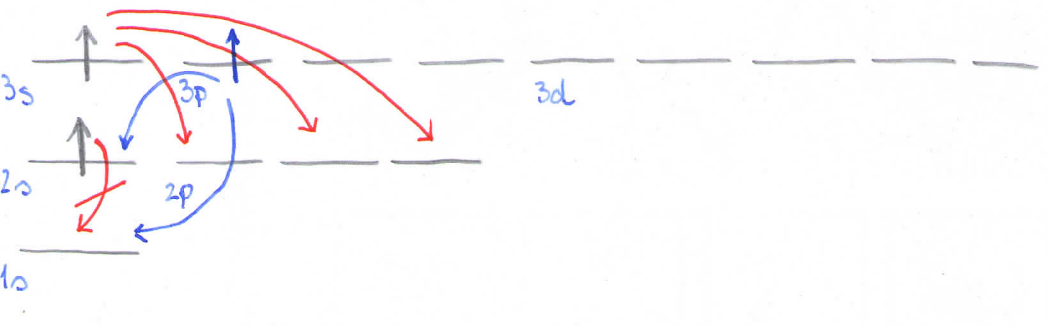
togi rotator :

$$\Delta l = \pm 1$$

$$\boxed{\begin{array}{l} \text{H atom:} \\ \Delta n - \text{poljuben} \\ \Delta l = \pm 1 \\ \Delta m = \pm 1, 0 \end{array}}$$

izbirno pravilo za el. dipol. prehod

VODIKOV ATOM :



$$\boxed{I_{e.d.} : I_{m.d.} : I_{e.q.} = 1 : 10^{-5} : 10^{-7}}$$

intenzitete
el. dipol. prehodov,
mag. dipol. prehodov,
el. kvadropol. prehodov

$\boxed{\text{SPIN fotona je 1.}}$