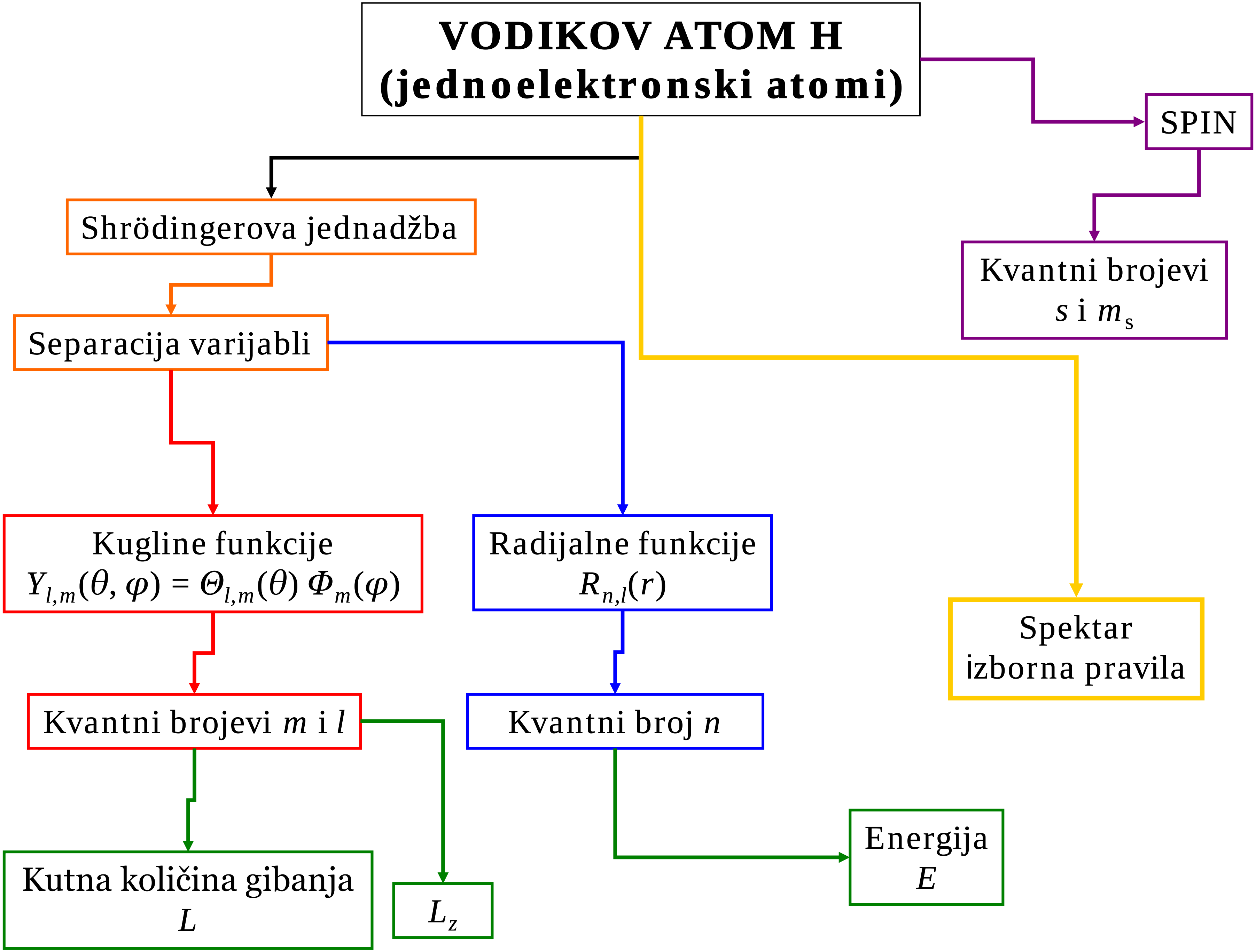
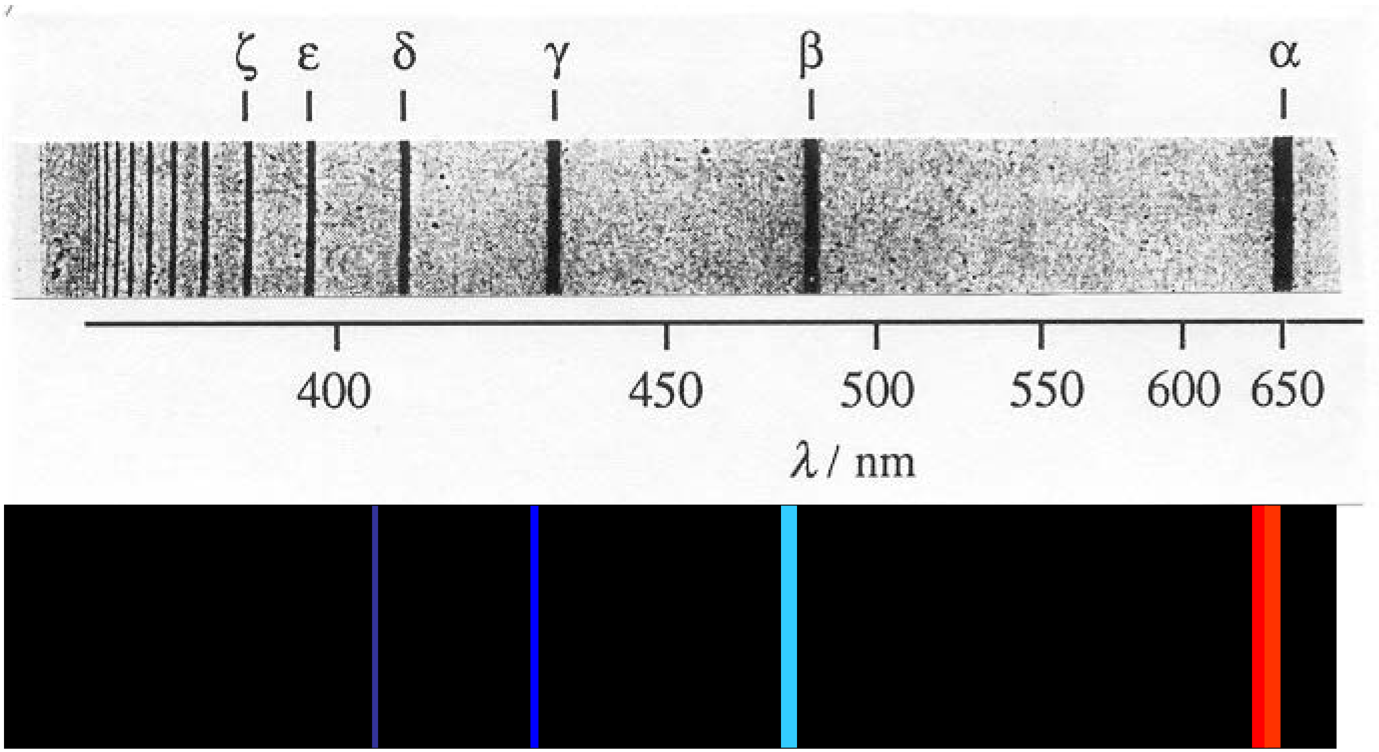

VODIKOV ATOM H
(jednoelektronski atomi)
SPIN
Kvantni brojevi
s i m_s
Shrödingerova jednadžba
Separacija varijabli
Kugline funkcije
$Y_{l,m}(\theta, \varphi) = \Theta_{l,m}(\theta)\,\Phi_m(\varphi)$
Radijalne funkcije
$R_{n,l}(r)$
Spektar
izborna pravila
Kvantni brojevi m i l
Kvantni broj n
Kutna količina gibanja
L
L_z
Energija
E

Atomski spektri - Balmerova serija



$$E_{\mathrm{e}} = -hcR_{\infty} \frac{\mu}{m_{\mathrm{e}}} \cdot \frac{1}{n^2}$$

Shrödingerova jednadžba za jednoelektronske atome

$$i) \qquad H = \frac{p_{\mathrm{e}}^2}{2m_{\mathrm{e}}} + \frac{p_{\mathrm{N}}^2}{2m_{\mathrm{N}}} - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

$$ii) \qquad \hat{H} = -\frac{\hbar^2}{2m_{\mathrm{e}}}\nabla_{\mathrm{e}}^2 + -\frac{\hbar^2}{2m_{\mathrm{N}}}\nabla_{\mathrm{N}}^2 - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

$$iii) \qquad \hat{H} = -\frac{\hbar^2}{2m_{\mathrm{e}}}\nabla_{\mathrm{e}}^2\Psi + -\frac{\hbar^2}{2m_{\mathrm{N}}}\nabla_{\mathrm{N}}^2\Psi - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\Psi = E\Psi$$

-odvajanje translacije od internog gibanja i uvođenje reducirane mase

$$iv) \qquad X = \frac{m_{\mathrm{e}}x_{\mathrm{e}} + m_{\mathrm{N}}x_{\mathrm{N}}}{m_{\mathrm{e}} + m_{\mathrm{N}}},\ Y = \frac{m_{\mathrm{e}}y_{\mathrm{e}} + m_{\mathrm{N}}y_{\mathrm{N}}}{m_{\mathrm{e}} + m_{\mathrm{N}}},\ Z = \frac{m_{\mathrm{e}}z_{\mathrm{e}} + m_{\mathrm{N}}z_{\mathrm{N}}}{m_{\mathrm{e}} + m_{\mathrm{N}}}$$

$$x = x_{\mathrm{e}} - x_{\mathrm{N}},\ y = y_{\mathrm{e}} - y_{\mathrm{N}},\ z = z_{\mathrm{e}} - z_{\mathrm{N}}$$

$$\Psi(X, Y, Z, x, y, z) = \Psi(X)\Psi(Y)\Psi(Z)\psi(x, y, z)$$

Schrödingerova jednadžba za interno gibanje → separacija varijabli → polarne koordinate

$$v) \qquad \hat{H} = -\frac{\hbar^2}{2\mu}\nabla^2\psi - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\psi = E_{\mathrm{e}}\psi$$

Polarne koordinate

$$r = \sqrt{x^2 + y^2 + z^2}$$

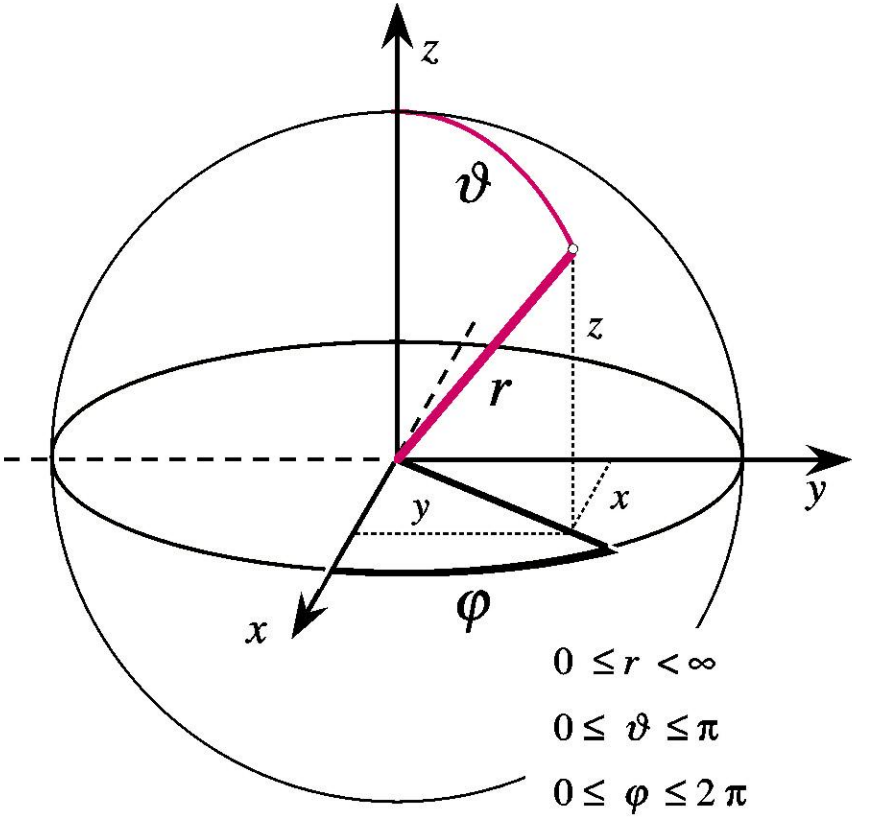
$$\vartheta = \arctan\left\{\left(\frac{x^2 + y^2}{z^2}\right)^{1/2}\right\}$$

$$\varphi = \arctan\left(\frac{y}{x}\right)$$

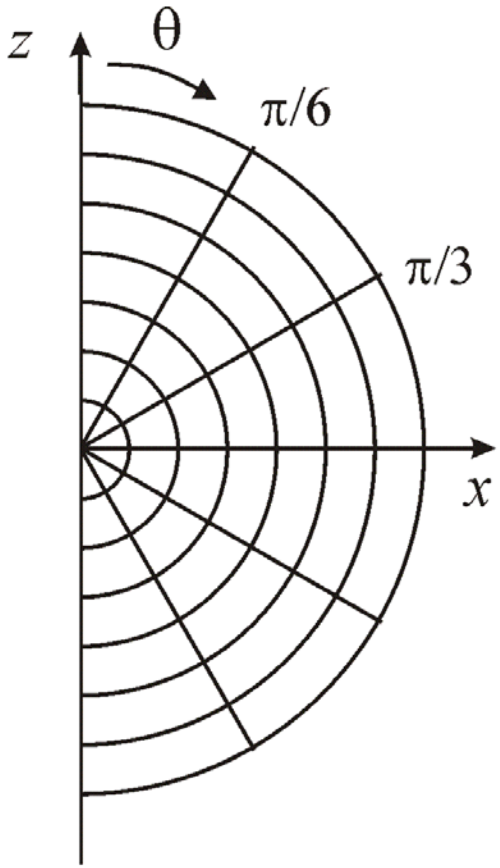
$$x = r\sin\vartheta\cos\varphi$$

$$y = r\sin\vartheta\sin\varphi$$

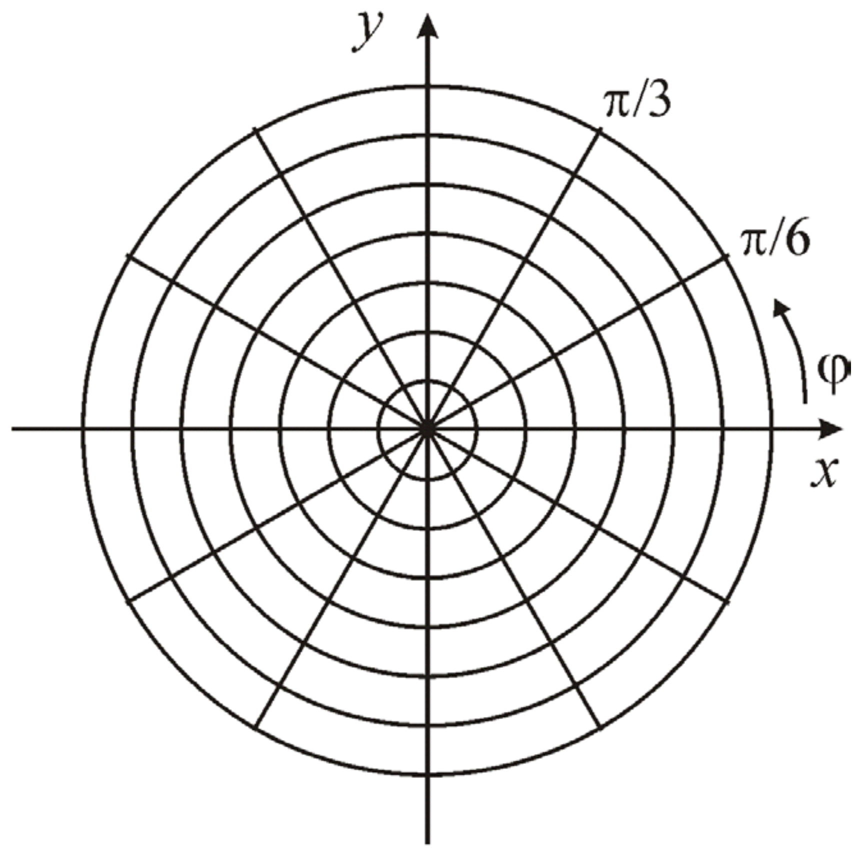
$$z = r\cos\vartheta$$



Polarne koordinate



θ

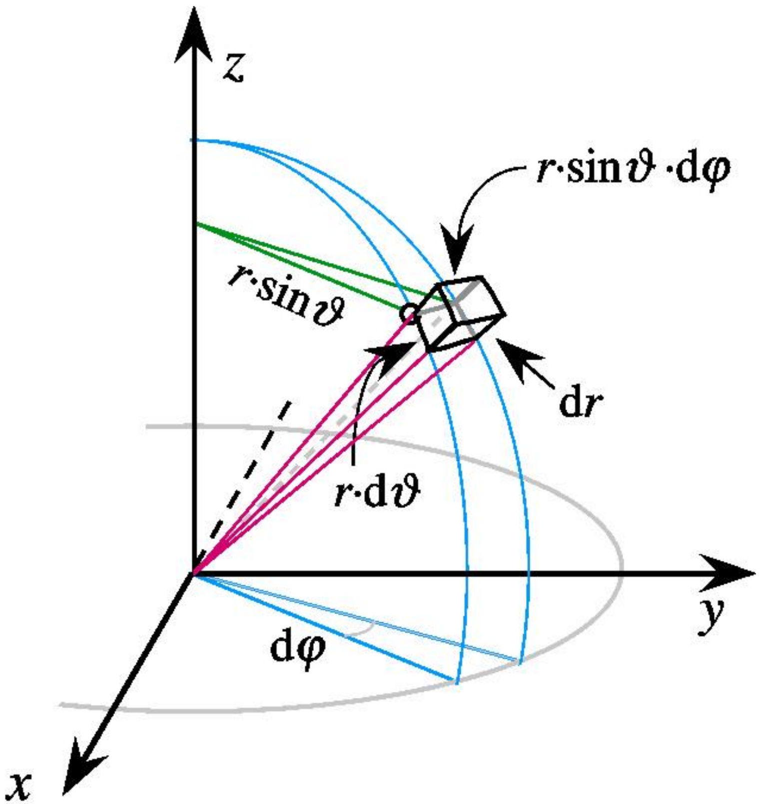


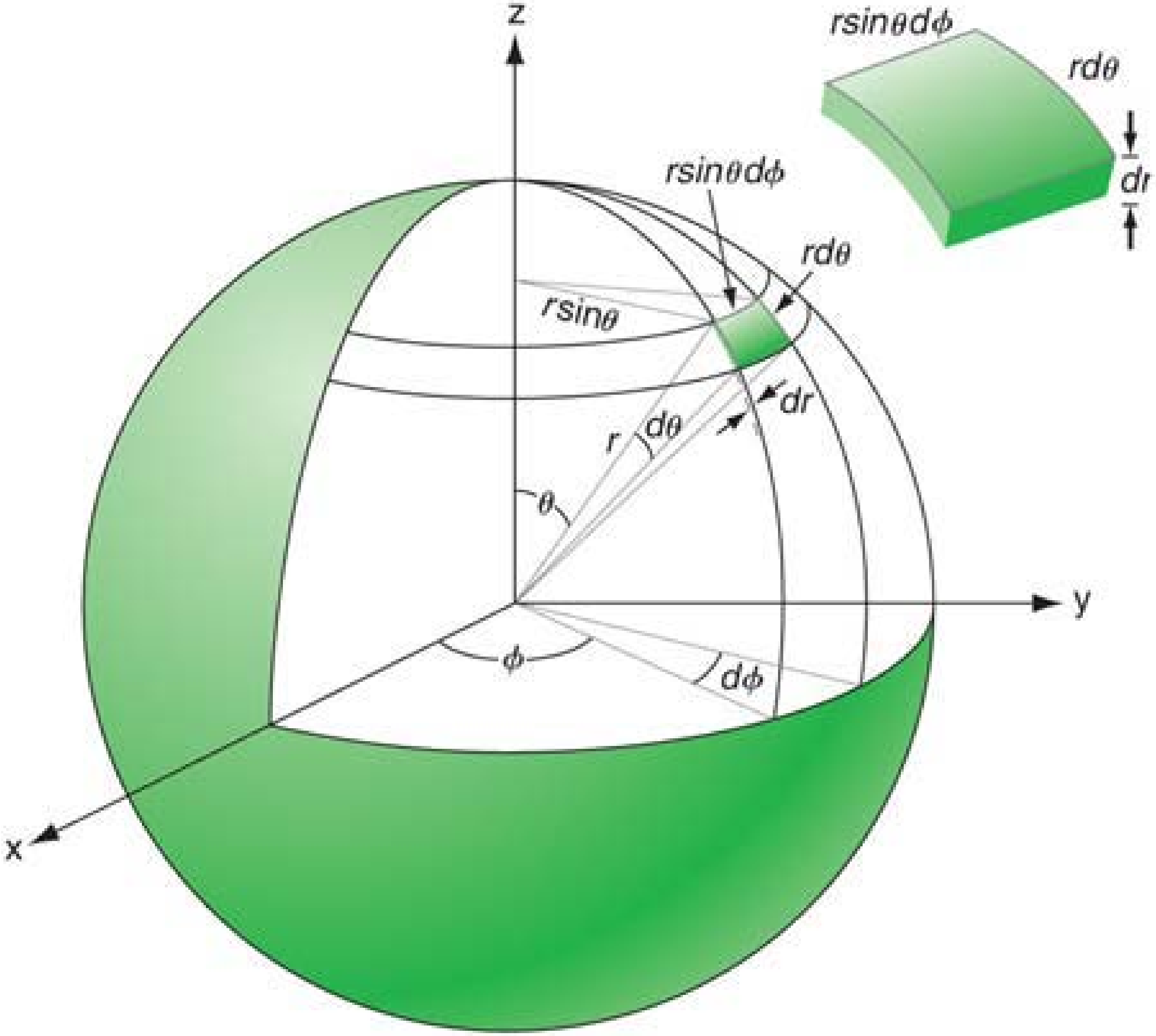
φ

Element prostora

$$\mathrm{d}\tau = \mathrm{d}r \cdot r\,\mathrm{d}\vartheta \cdot r\sin\vartheta\,\mathrm{d}\varphi$$

$$= r^2 \sin\vartheta\,\mathrm{d}\varphi\,\mathrm{d}\vartheta\,\mathrm{d}r$$




z
y
x
rsinθdϕ
rdθ
dr
rsinθdϕ
rdθ
rsinθ
dr
r
dθ
θ
ϕ
dϕ

$$\nabla^2 = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) - \frac{1}{r^2}\frac{\hat{L}^2}{\hbar^2}$$

$$\hat{L}^2 = -\hbar^2\left\{\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial}{\partial\theta}) + \frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\varphi^2}\right\}$$

$$\Psi(r,\vartheta,\varphi) = R(r)\cdot\Phi(\varphi)\cdot\Theta(\vartheta)$$

$$\frac{-\hbar^2}{2\mu r^2}\left\{\frac{\partial}{\partial r}\left(r^2\frac{\partial\psi}{\partial r}\right) - \frac{\hat{L}^2\psi}{\hbar^2}\right\} - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2\psi}{r} = E_\mathrm{e}\psi$$

$$-\hbar^2\left\{\frac{\partial}{\partial r}\left(r^2\frac{\partial R(r)}{\partial r}\right)\right\}\cdot\Phi(\varphi)\cdot\Theta(\vartheta) - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2R(r)\cdot\Phi(\varphi)\cdot\Theta(\vartheta)}{r} - 2\mu r^2E_\mathrm{e}R(r)\cdot\Phi(\varphi)\cdot\Theta(\vartheta) = \hat{L}^2R(r)\cdot\Phi(\varphi)\cdot\Theta(\vartheta)$$

$$\frac{-\hbar^2}{R(r)}\left\{\frac{\partial}{\partial r}\left(r^2\frac{\partial R(r)}{\partial r}\right)\right\} - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r} - 2\mu r^2E_\mathrm{e} = \frac{\hat{L}^2\Phi(\varphi)\cdot\Theta(\vartheta)}{\Phi(\varphi)\cdot\Theta(\vartheta)}$$

$$\frac{-\hbar^2}{2\mu r^2}\left\{\frac{\mathrm{d}^2R(r)}{\mathrm{d}r^2} + \frac{2}{r}\frac{\mathrm{d}R(r)}{\mathrm{d}r} + \frac{\beta}{r^2}R(r)\right\} - \frac{1}{4\pi\varepsilon_0}\frac{Ze^2R(r)}{r} = E_\mathrm{e}R(r)$$

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial Y}{\partial\theta}) + \frac{1}{\sin^2\theta}\frac{\partial^2Y}{\partial\varphi^2} = -\beta Y;\ \ Y = \Phi(\varphi)\cdot\Theta(\vartheta)$$

$$Y(\theta,\varphi)=\Phi(\varphi)\cdot\Theta(\vartheta)$$

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial Y}{\partial\theta})+\frac{1}{\sin^2\theta}\frac{\partial^2 Y}{\partial\varphi^2}=-\beta Y$$

$$\frac{\sin\theta}{\Theta}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial\Theta}{\partial\theta})+\beta\sin^2\theta=-\frac{1}{\Phi}\frac{\partial^2\Phi}{\partial\varphi^2}=\alpha$$

$$\frac{d^2\Phi(\varphi)}{d\varphi^2}=-\alpha\Phi(\varphi)$$

$$\frac{\sin\theta}{\Theta(\vartheta)}\frac{\partial}{\partial\theta}(\sin\theta\frac{\partial\Theta(\vartheta)}{\partial\theta})+\beta\sin^2\theta=-\frac{1}{\Phi}\frac{\partial^2\Phi(\varphi)}{\partial\varphi^2}=\alpha$$

$$\frac{d^2\Theta(\vartheta)}{d\theta^2}+\frac{\cos\theta}{\sin\theta}\frac{d\Theta(\vartheta)}{d\theta})-\frac{\alpha}{\sin^2\theta}\Theta(\vartheta)+\beta\Theta(\vartheta)=0$$

$$\frac{d^2\Phi(\varphi)}{d\varphi^2} = -\alpha\Phi(\varphi)$$

$\Phi(\varphi)$ periodička za $\alpha = m^2; m = 0, \pm 1, \pm 2, \ldots$

$m = 0, \pm 1, \pm 2$

$l \geq |m|$

n iznosi minimalno $l + 1$

$\Rightarrow$

$n = 1, 2, 3, \ldots$

$l = 0, 1, \ldots, n-1$

$m_l = -l, -l+1, \ldots, +l$

$$\Psi_{n,l,m}(r,\vartheta,\varphi) = \Phi_m(\varphi) \cdot \Theta_{l,m}(\vartheta) \cdot R_{n,l}(r)$$

$$E_\mathrm{e} = -hcZ^2 R_\infty \frac{\mu}{m_\mathrm{e}} \cdot \frac{1}{n^2}$$

Rješenja Φ

$$\Phi_m(\varphi) = \frac{1}{\sqrt{2\pi}}\,\mathrm{e}^{\mathrm{i}m\varphi}$$

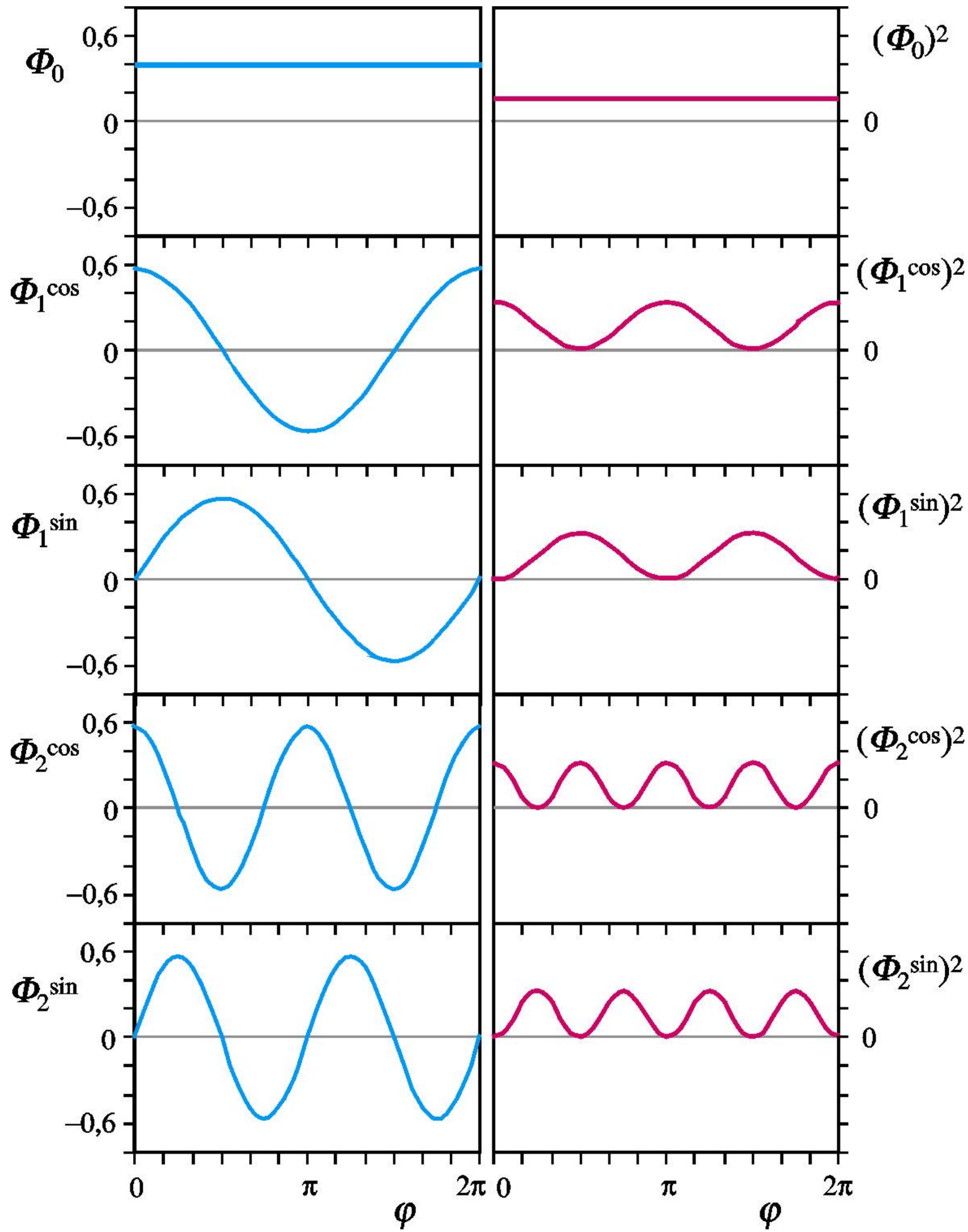
$$\Phi_m(\varphi) = \frac{1}{\sqrt{2\pi}}(\cos m\varphi + i\sin m\varphi)$$

$$\Phi_{|m|}^{\cos} = \frac{1}{\sqrt{2\pi}}\left\{\Phi_{|m|} + \Phi_{-|m|}\right\} = \frac{1}{\sqrt{\pi}}\cos(|m|\varphi)$$

$$\Phi_{|m|}^{\sin} = \frac{-\mathrm{i}}{\sqrt{2}}\left\{\Phi_{|m|} - \Phi_{-|m|}\right\} = \frac{1}{\sqrt{\pi}}\sin(|m|\varphi)$$

$m = 0, \pm 1, \pm 2, \pm 3, \ldots \pm l$

Φ



0,6
0
–0,6
Φ_0
$(\Phi_0)^2$
$\Phi_1^{\cos}$
$(\Phi_1^{\cos})^2$
$\Phi_1^{\sin}$
$(\Phi_1^{\sin})^2$
$\Phi_2^{\cos}$
$(\Phi_2^{\cos})^2$
$\Phi_2^{\sin}$
$(\Phi_2^{\sin})^2$
0
π
2π
φ

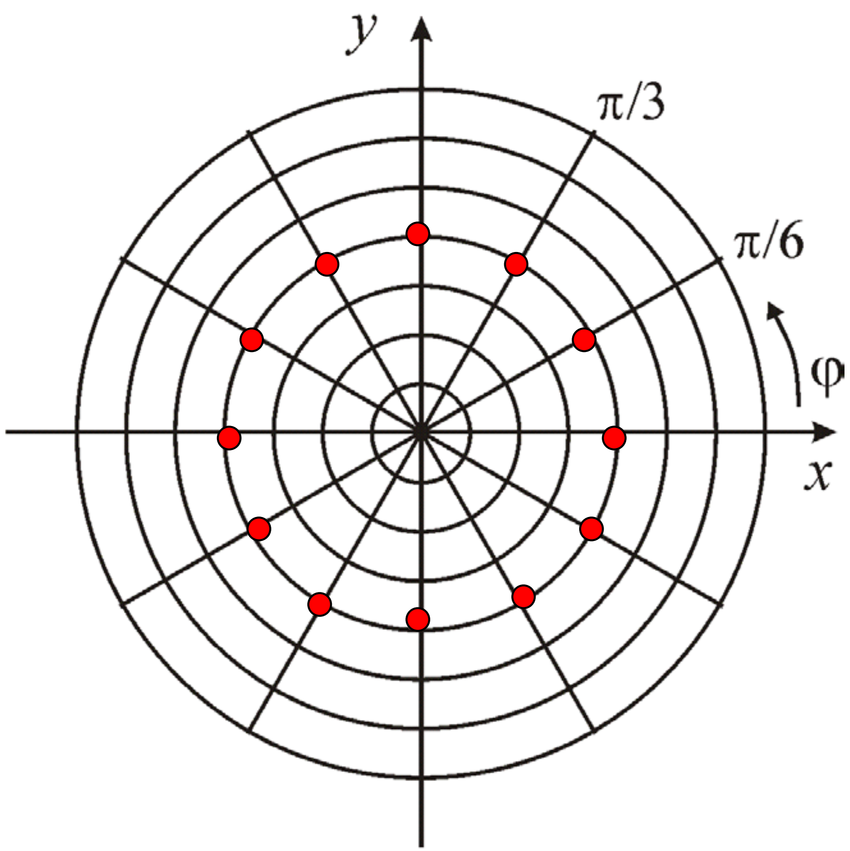
$$\Phi_m(\varphi) = \frac{1}{\sqrt{2\pi}} e^{im\varphi}$$

$$m = 0$$

$$\Phi_m(\varphi) = \frac{1}{\sqrt{2\pi}}$$

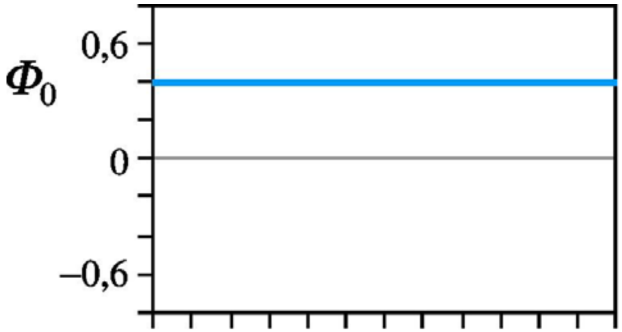
Φ

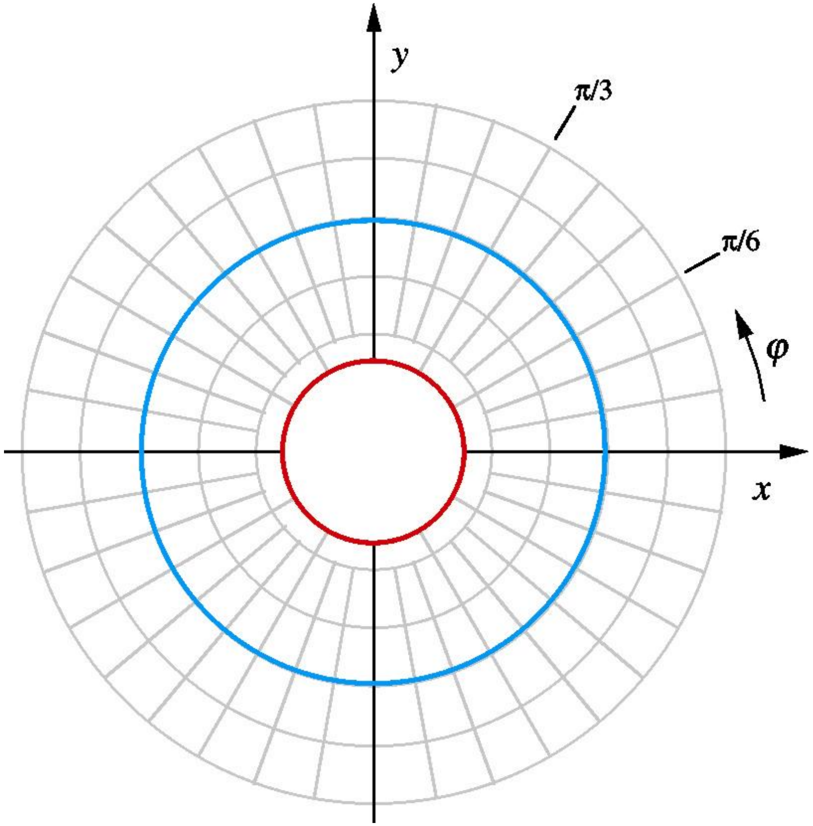
φ	φ	Φ
0	0	0,399
π/6	30°	0,399
π/3	60°	0,399
π/2	90°	0,399
4π/6	120°	0,399
5π/6	150°	0,399
π	180°	0,399
7π/6	210°	0,399
8π/6	240°	0,399
3π/2	270°	0,399
10π/6	300°	0,399
11π/6	330°	0,399



Φ

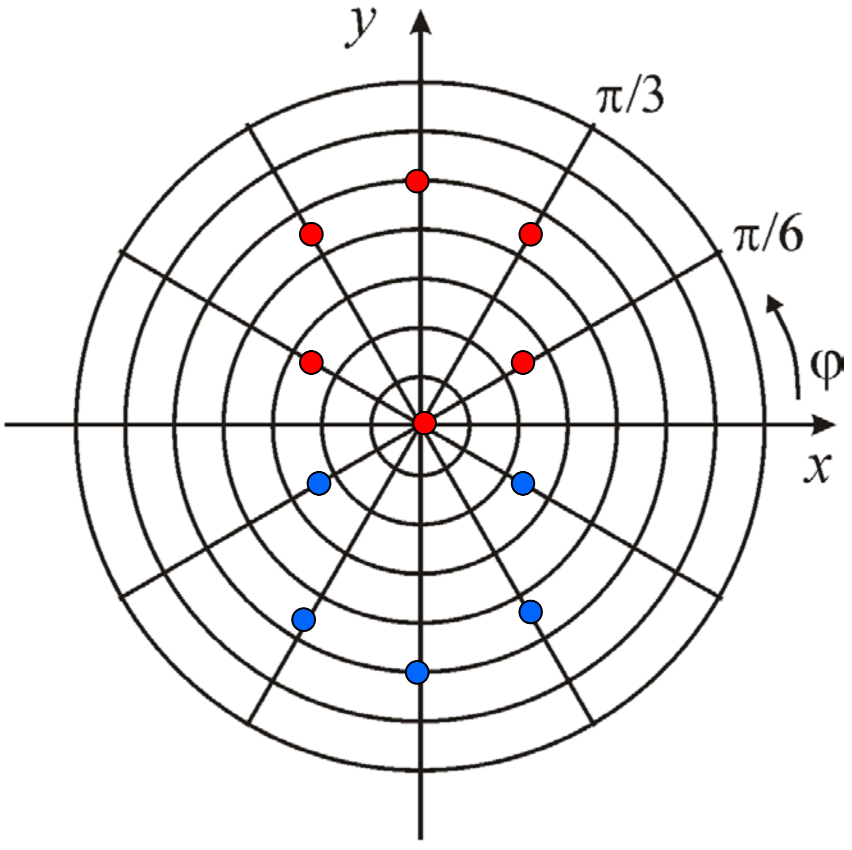
$m = 0 \qquad \Phi_0(\varphi) = \frac{1}{\sqrt{2\pi}}$



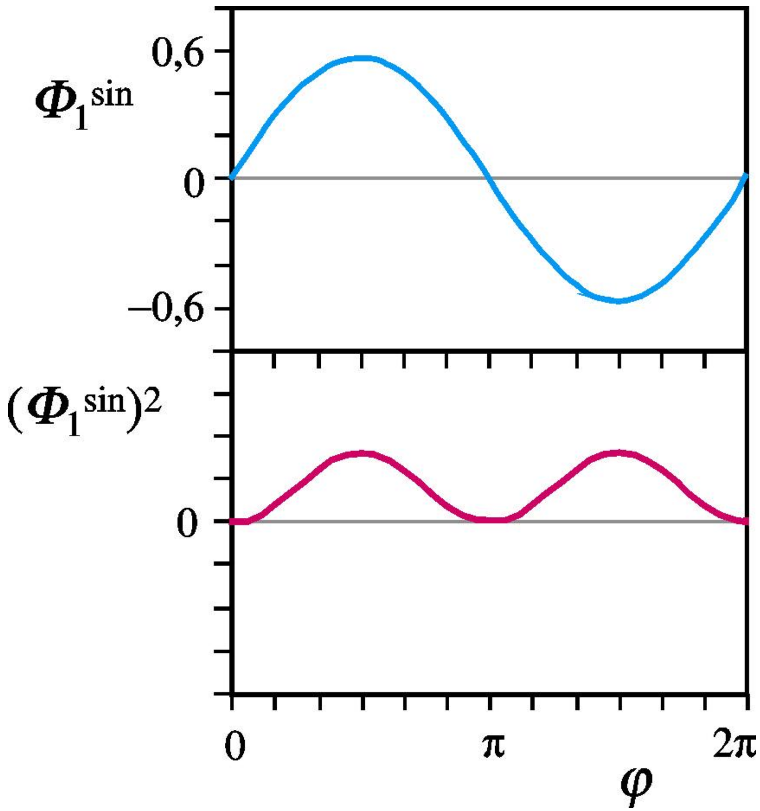


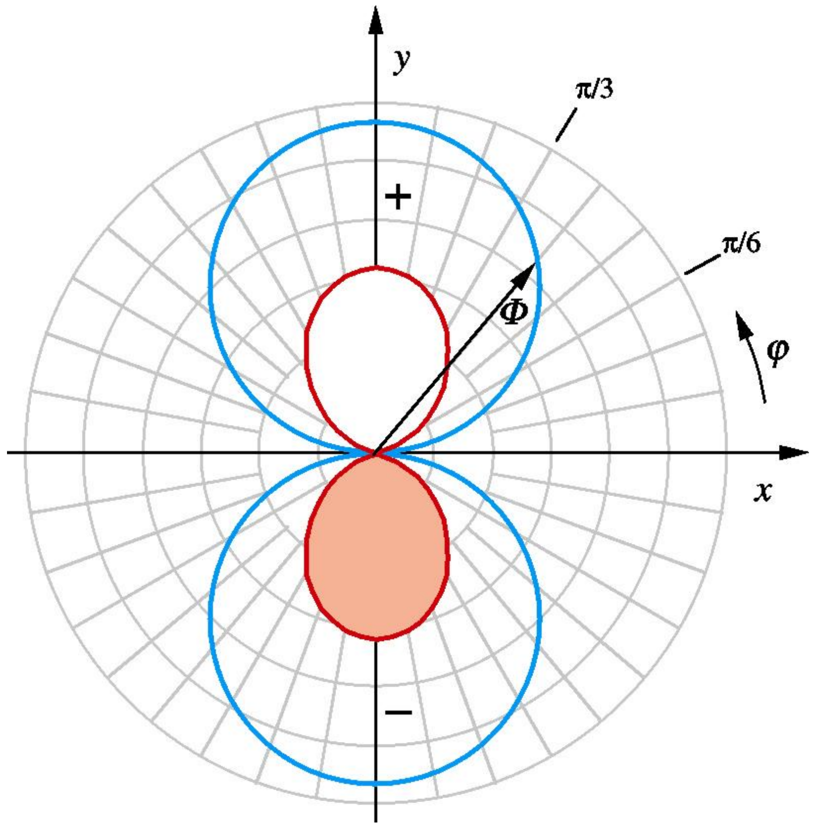
$m = -1$ $$\Phi_1^{\sin} = \frac{1}{\sqrt{\pi}} \sin(\varphi)$$

φ	φ	Φ
0	0	0
π/6	30°	0.28
π/3	60°	0.49
π/2	90°	0.56
π/6	120°	0.49
5π/6	150°	0.28
π	180°	0
7π/6	210°	-0.28
8π/6	240°	-0.49
3π/2	270°	-0.56
10π/6	300°	-0.49
11π/6	330°	-0.28

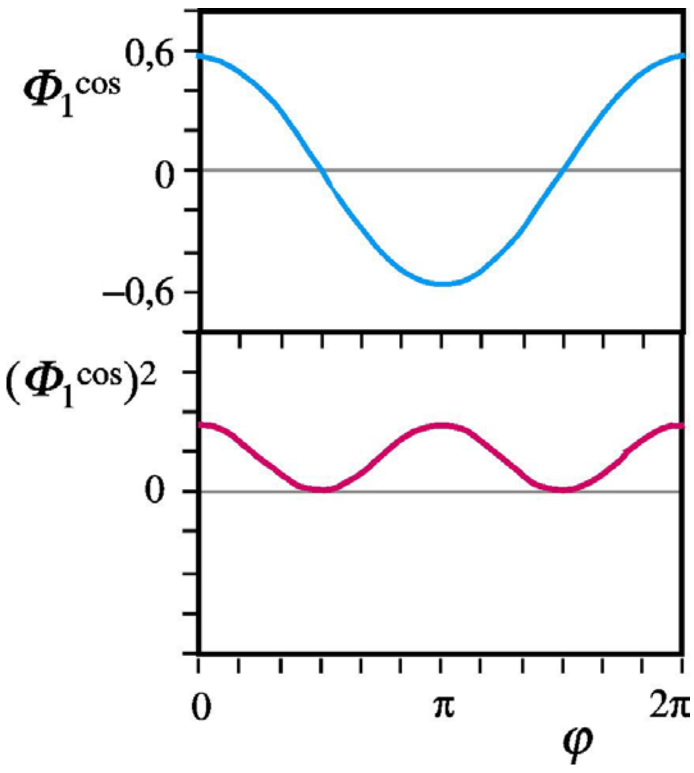


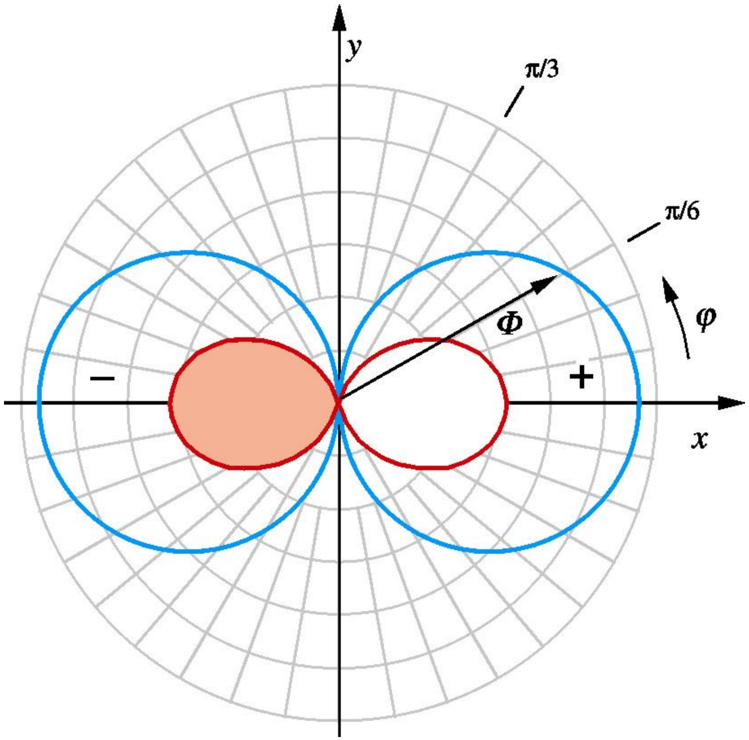
$$m = -1 \qquad \Phi_1^{\sin} = \frac{1}{\sqrt{\pi}}\sin(\varphi)$$





$m = +1 \qquad\qquad \Phi_1^{\cos} = \frac{1}{\sqrt{\pi}}\cos(\varphi)$





Rješenja Θ

$$l = 0; \quad m = 0; \quad \Theta_{0,0} = \frac{1}{\sqrt{2}}$$

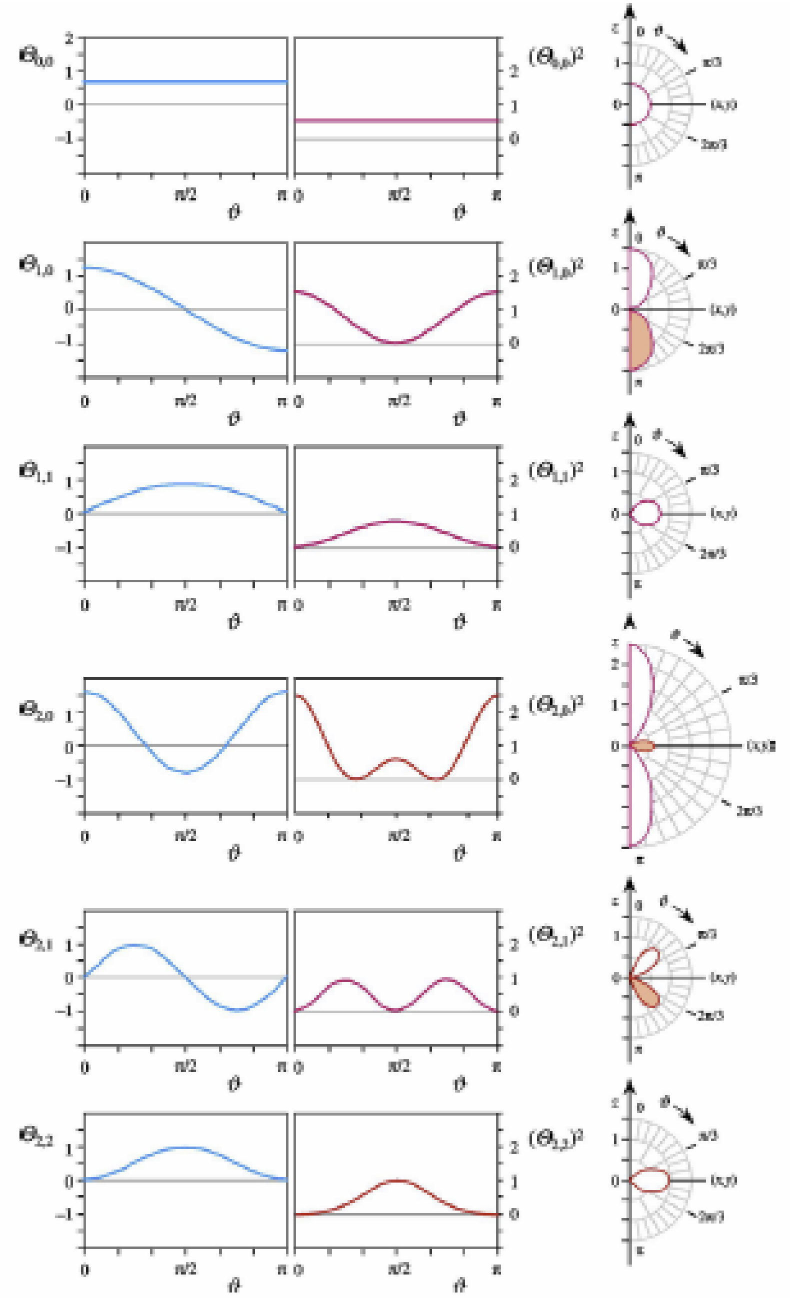
$$l = 1; \quad m = 0; \quad \Theta_{1,0} = \frac{\sqrt{6}}{2}\cos\vartheta$$

$$m = 1; \quad \Theta_{1,1} = \frac{\sqrt{3}}{2}\sin\vartheta$$

$$l = 2; \quad m = 0; \quad \Theta_{2,0} = \frac{\sqrt{10}}{4}(3\cos^2\vartheta - 1)$$

$$m = 1; \quad \Theta_{2,1} = \frac{\sqrt{15}}{2}\sin\vartheta\cos\vartheta$$

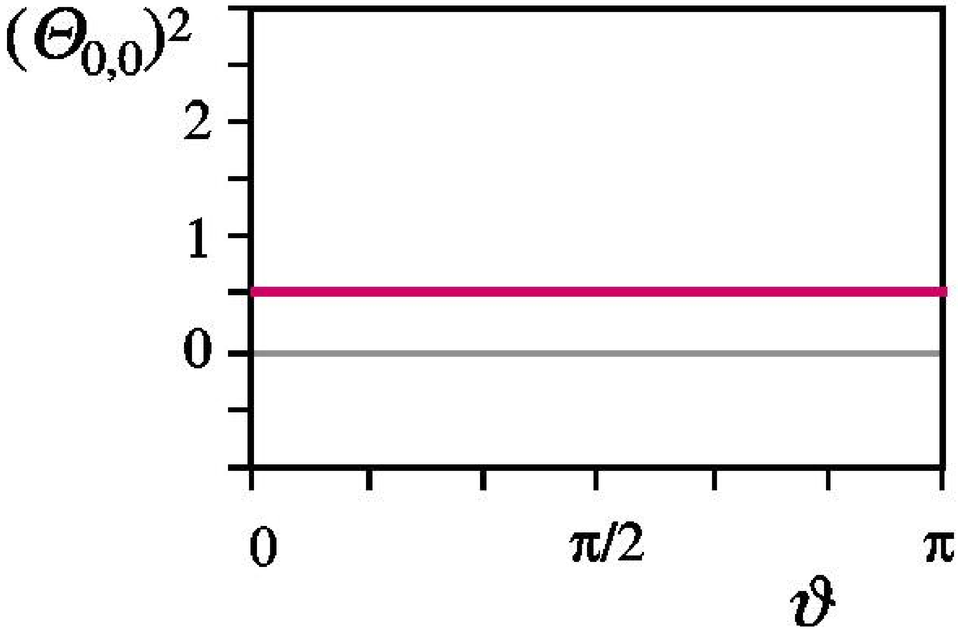
$$m = 2; \quad \Theta_{2,2} = \frac{\sqrt{15}}{4}\sin^2\vartheta$$

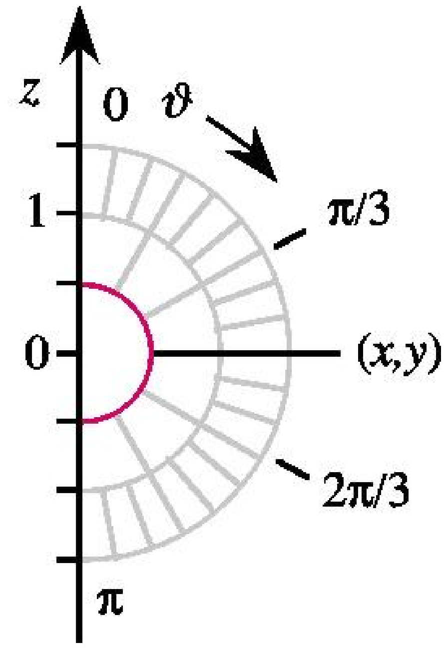


$l = 0, 1, 2, 3, ..., n-1$

Θ

$l = 0, m = 0$ $\Theta_{0,0} = \frac{1}{\sqrt{2}}$



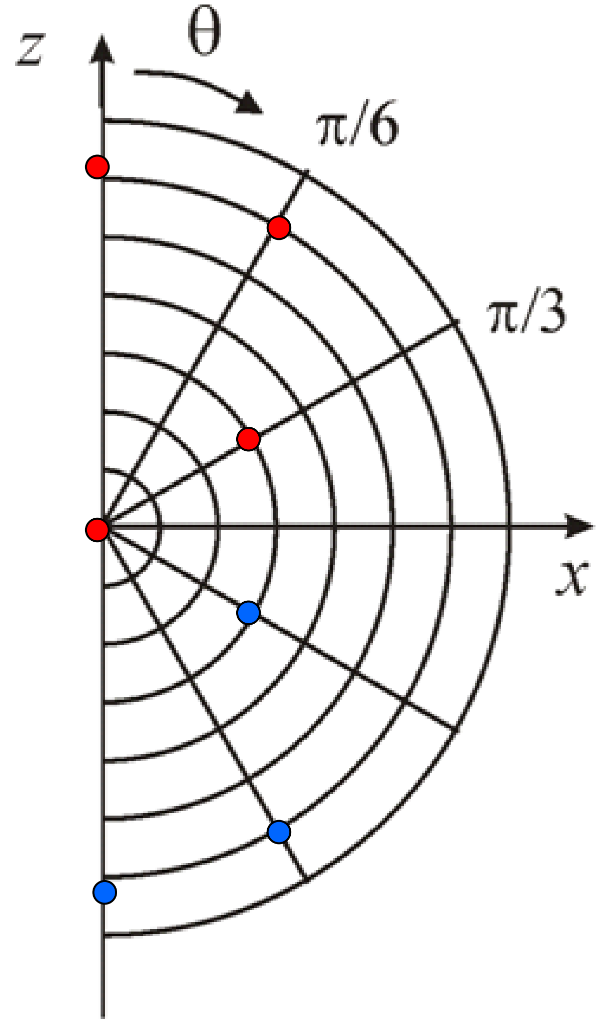


Θ

$l = 1, m = 0$

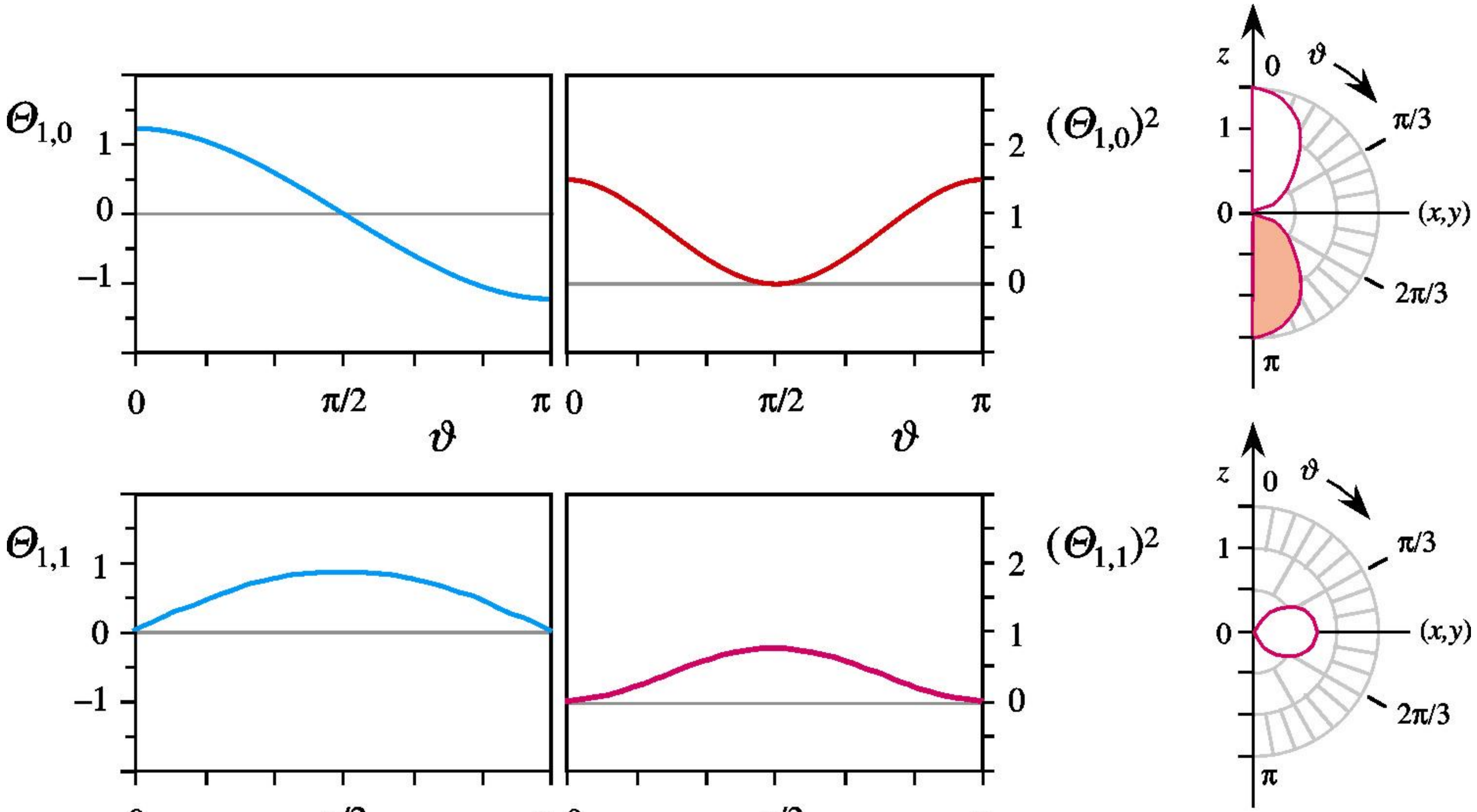
$$\Theta_{1,0} = \frac{\sqrt{6}}{2}\cos\vartheta$$

ϑ	ϑ	θ
0	0	1.2
π/6	30°	1.1
π/3	60°	0.6
π/2	90°	0
4π/6	120°	-0.6
5π/6	150°	-1.1
π	180°	-1.2



$l = 1,\ m = 1$

$$\Theta_{1,0} = \frac{\sqrt{6}}{2}\cos\vartheta \qquad \Theta_{1,1} = \frac{\sqrt{3}}{2}\sin\vartheta$$

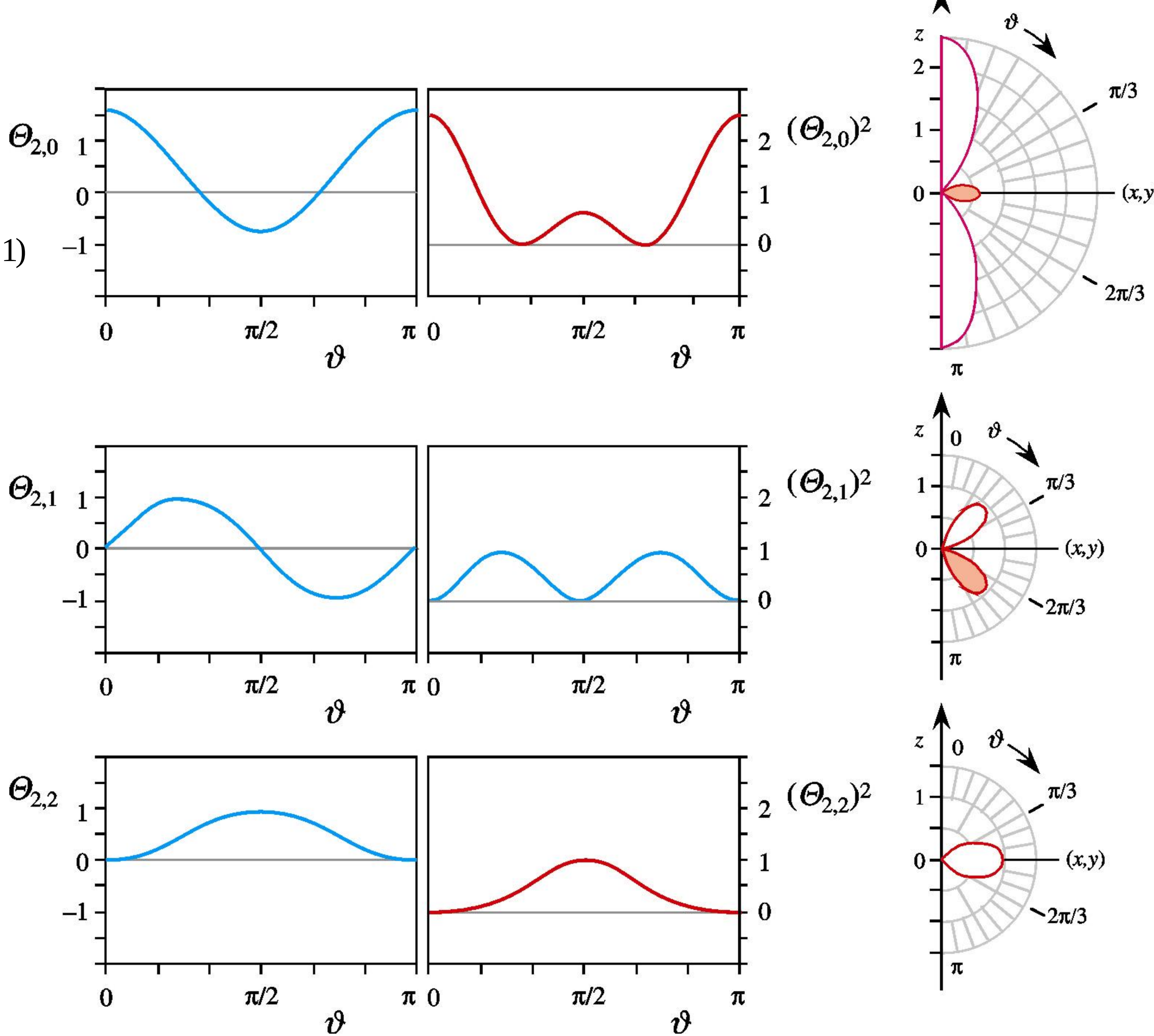


$l = 2$

$$\Theta_{2,0} = \frac{\sqrt{10}}{4}(3\cos^2\vartheta - 1)$$

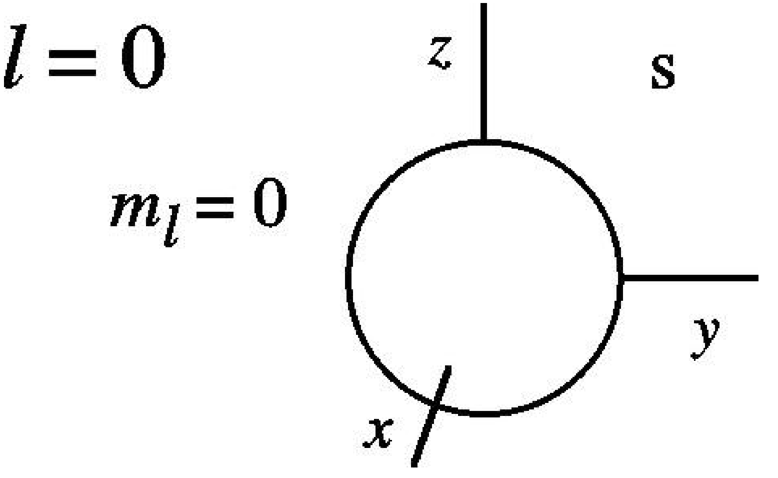
$$\Theta_{2,1} = \frac{\sqrt{15}}{2}\sin\vartheta\cos\vartheta$$

$$\Theta_{2,2} = \frac{\sqrt{15}}{4}\sin^2\vartheta$$



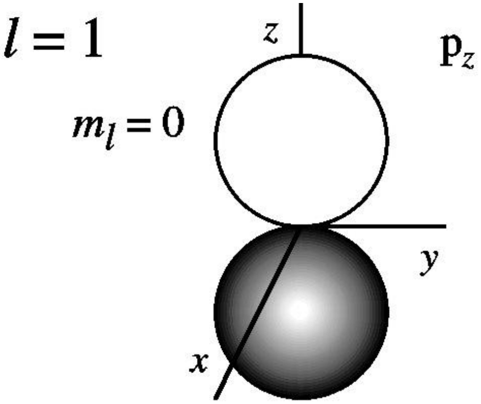
Kugline funkcije

$$Y_{0,0} = \frac{1}{2\sqrt{\pi}}$$



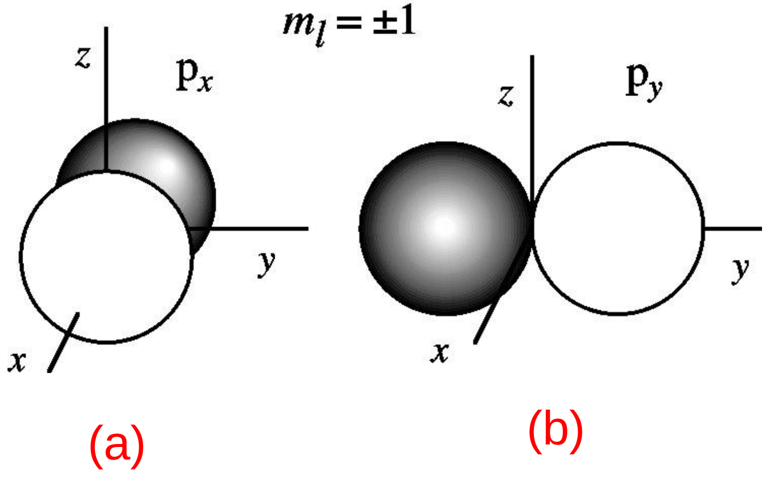
Kugline funkcije

$$Y_{1,0} = \frac{1}{2}\sqrt{\frac{3}{\pi}}\cos\vartheta$$



(a) $$Y_{1,1}^{\cos} = \frac{1}{2}\sqrt{\frac{3}{\pi}}\sin\vartheta\cos\varphi$$

(b) $$Y_{1,1}^{\sin} = \frac{1}{2}\sqrt{\frac{3}{\pi}}\sin\vartheta\sin\varphi$$



Kugline funkcije

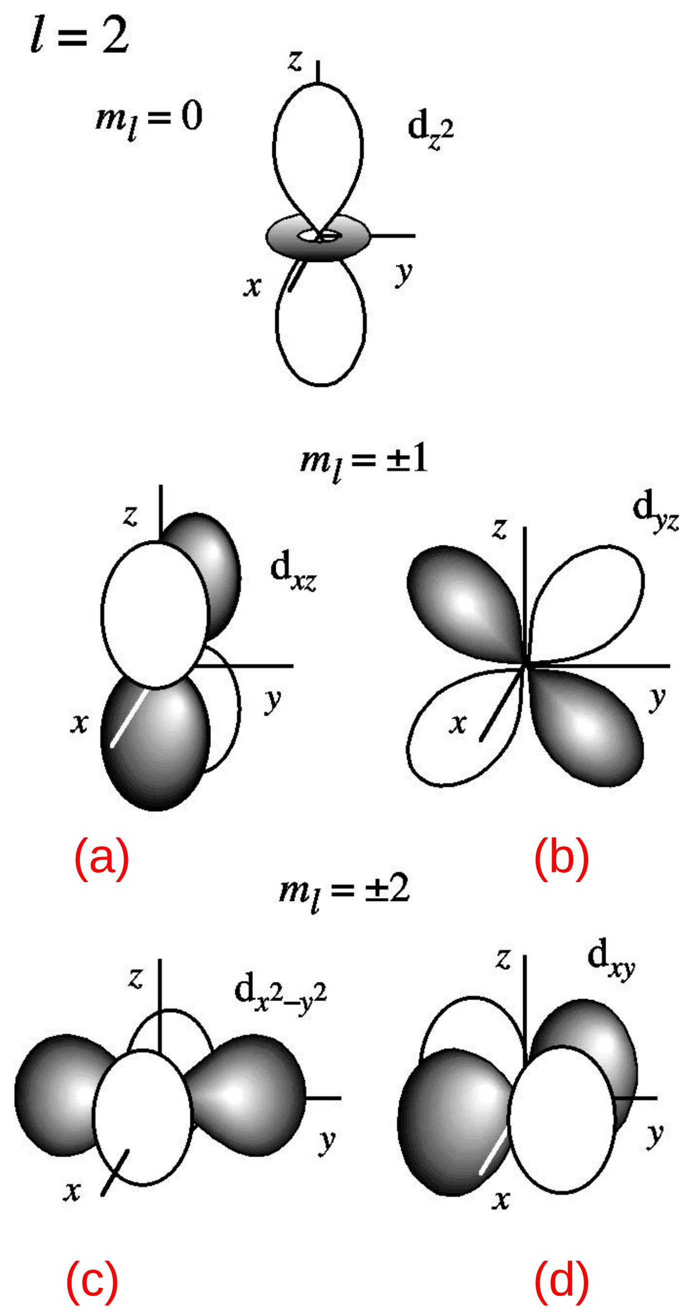
$$Y_{2,0} = \frac{1}{4}\sqrt{\frac{5}{\pi}}\,(3\cos^2\vartheta - 1)$$

(a) $$Y_{2,1}^{\cos} = \frac{1}{2}\sqrt{\frac{15}{\pi}}\,\sin\vartheta\cos\vartheta\cos\varphi$$

(b) $$Y_{2,1}^{\sin} = \frac{1}{2}\sqrt{\frac{15}{\pi}}\,\sin\vartheta\cos\vartheta\sin\varphi$$

(c) $$Y_{2,2}^{\cos} = \frac{1}{4}\sqrt{\frac{15}{\pi}}\,\sin^2\vartheta\cos 2\varphi$$

(d) $$Y_{2,2}^{\sin} = \frac{1}{4}\sqrt{\frac{15}{\pi}}\,\sin^2\vartheta\sin 2\varphi$$



Radijalne funkcije

Orbitala	n	l	Radijalna funkcija*, $R_{n,l}$
1s	1	0	$2\left(\frac{Z}{a_0}\right)^{3/2} e^{-\rho}$
2s	2	0	$\frac{1}{2\sqrt{2}}\left(\frac{Z}{a_0}\right)^{3/2} (2-\rho)\, e^{-\rho/2}$
2p	2	1	$\frac{1}{2\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2} \rho\, e^{-\rho/2}$
3s	3	0	$\frac{2}{81\sqrt{3}}\left(\frac{Z}{a_0}\right)^{3/2} (27-18\rho+2\rho^2)\, e^{-\rho/3}$
3p	3	1	$\frac{4}{81\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2} (6\rho-\rho^2)\, e^{-\rho/3}$
3d	3	2	$\frac{4}{81\sqrt{30}}\left(\frac{Z}{a_0}\right)^{3/2} \rho^2\, e^{-\rho/3}$

$\sim \boldsymbol{\rho^0 \exp(-\rho)}$

$\sim \boldsymbol{\rho^1 \exp(-\rho)}$

$\sim \boldsymbol{\rho^2 \exp(-\rho)}$

$$\rho = \frac{Zr}{a_0}$$

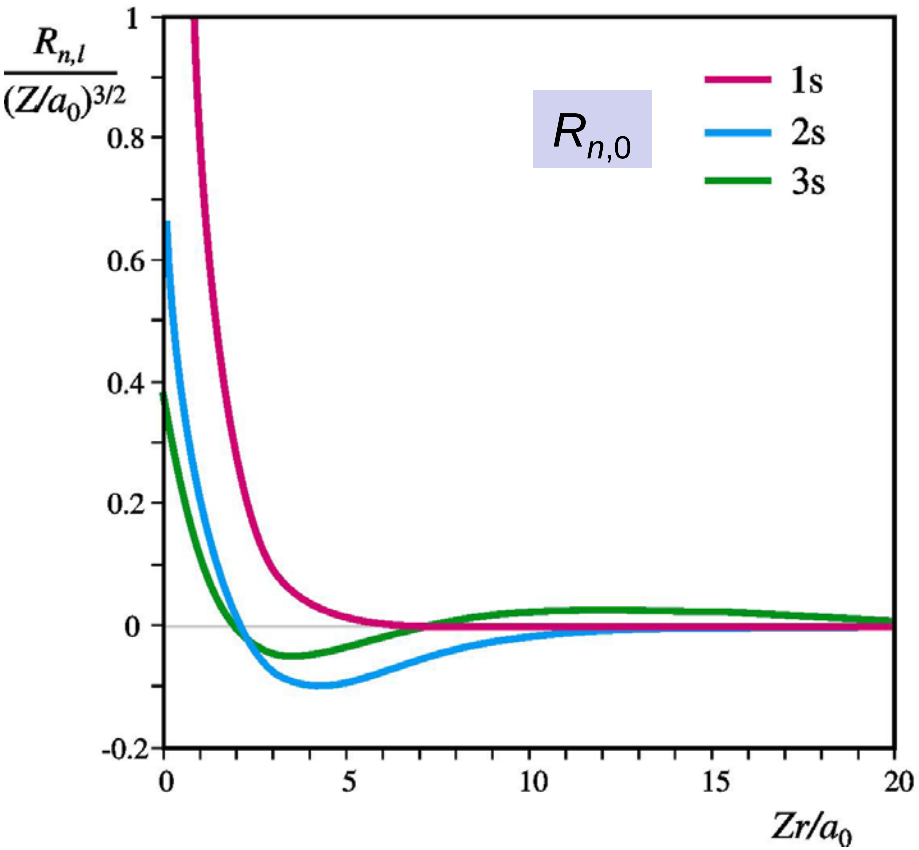
Radijalne funkcije

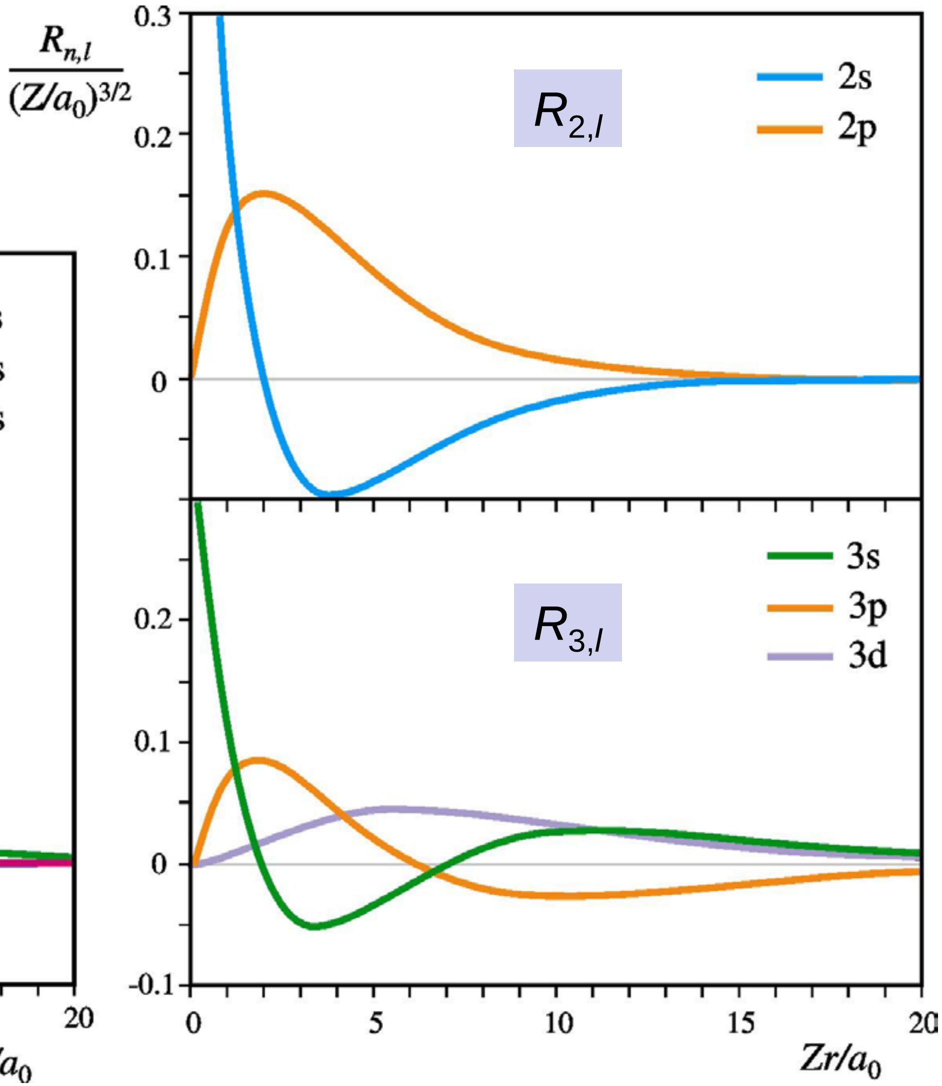
$$R_{1,0} = 2\left(\frac{Z}{a_0}\right)^{3/2} \mathrm{e}^{-\rho}$$

$$R_{2,0} = \frac{1}{2\sqrt{2}}\left(\frac{Z}{a_0}\right)^{3/2} (2-\rho)\,\mathrm{e}^{-\rho/2}$$

$$R_{2,1} = \frac{1}{2\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2} \rho\,\mathrm{e}^{-\rho/2}$$

Radijalne funkcije





Radijalne funkcije

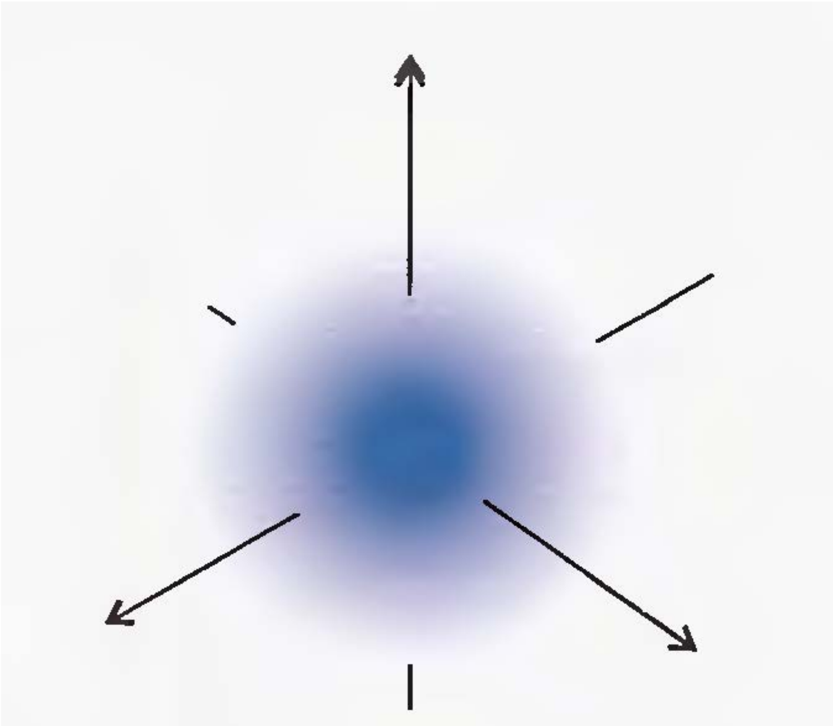
- samo **s** orbitale (*l* = 0) imaju značajniju vrijednost u blizini jezgre

- radijalne funkcije proporcionalne s r^l – elektroni s većim vrijednostima *l* sve se manje zadržavaju u blizini jezgre

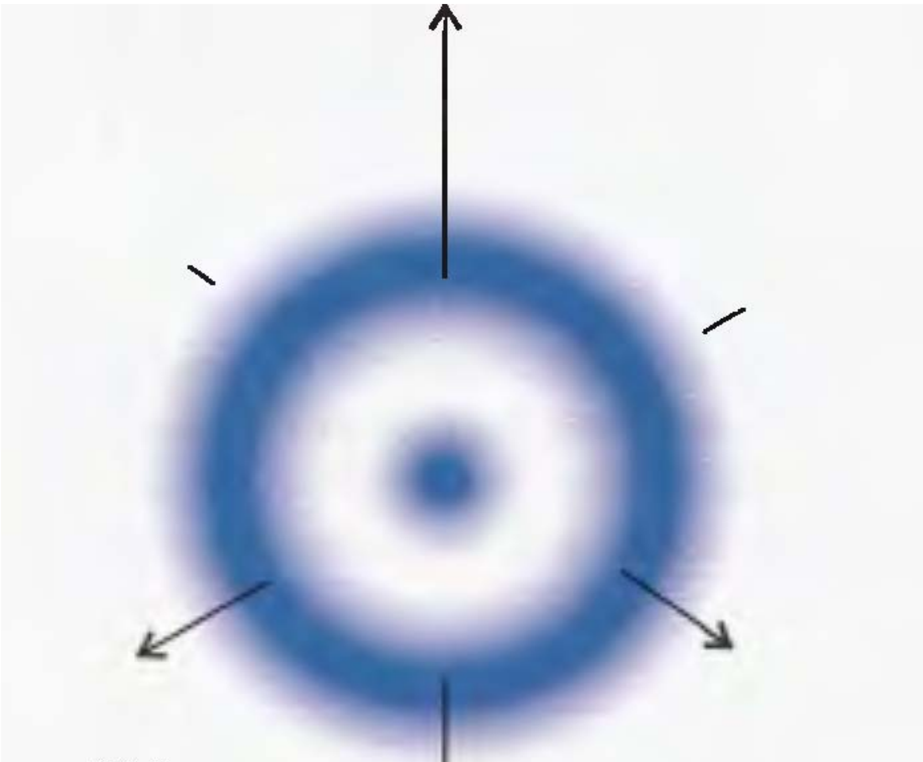
- valna funkcija sve je položenija što su kvantni brojevi veći (položenija valna funkcija – manja kinetička energija)

-na jezgru djeluju **s**-elektroni i jezgra djeluje najviše na **s**-elektrone

- energija raste s brojem čvornih točaka (čvornih ploha) – za neki *l* broj čvornih ploha raste s glavnim kvantnim brojem *n*.



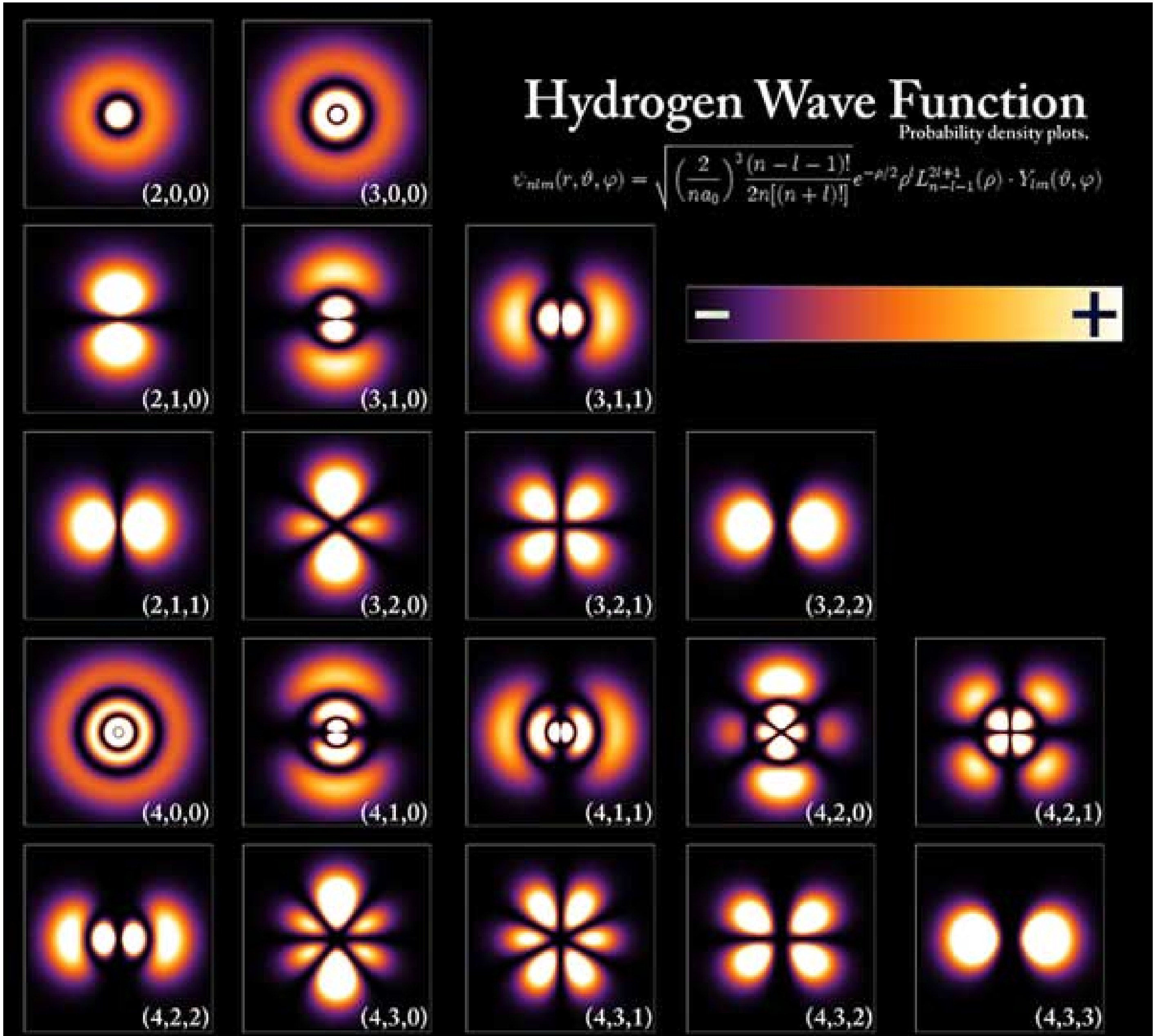
(a) 1*s*

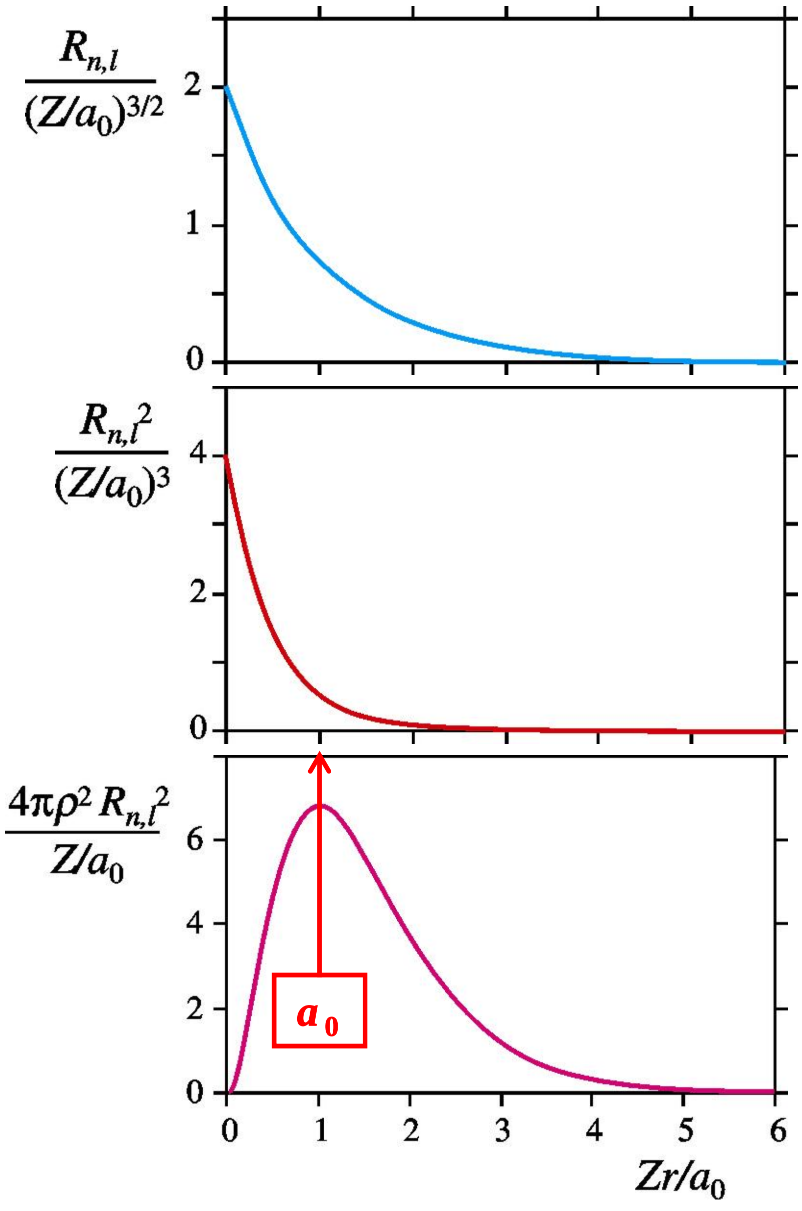


(b) 2*s*

$$\Psi_{1s} = \frac{1}{\sqrt{\pi a_0^3}} e^{-r/a_0}$$

$$\Psi_{2s} = \frac{1}{4\sqrt{2\pi a_0^3}} (2 - r) = e^{-r/2a_0}$$


Hydrogen Wave Function
Probability density plots.
$\psi_{nlm}(r,\vartheta,\varphi)=\sqrt{\left(\frac{2}{na_0}\right)^3\frac{(n-l-1)!}{2n[(n+l)!]}}e^{-\rho/2}\rho^l L^{2l+1}_{n-l-1}(\rho)\cdot Y_{lm}(\vartheta,\varphi)$
−
+
(2,0,0)
(3,0,0)
(2,1,0)
(3,1,0)
(3,1,1)
(2,1,1)
(3,2,0)
(3,2,1)
(3,2,2)
(4,0,0)
(4,1,0)
(4,1,1)
(4,2,0)
(4,2,1)
(4,2,2)
(4,3,0)
(4,3,1)
(4,3,2)
(4,3,3)



Radijalna funkcija

Kvadrat radijalne funkcije (elektronska gustoća)

- vjerojatnost nalaženja elektrona u elementu prostora dτ oko točke u prostoru s koordinatama r, ϑ i φ.

Radijalna gustoća vjerojatnosti

- na kojoj udaljenosti od jezgre r je najveća vjerojatnost nalaženje elektrona?
- integracija preko svih ϑ i φ
- volumen sloja kugle polumjera r i debljine dr

$\psi^2 \mathrm{d}\tau =$ vjerojatnost nalaženja elektrona u elementu prostora dτ

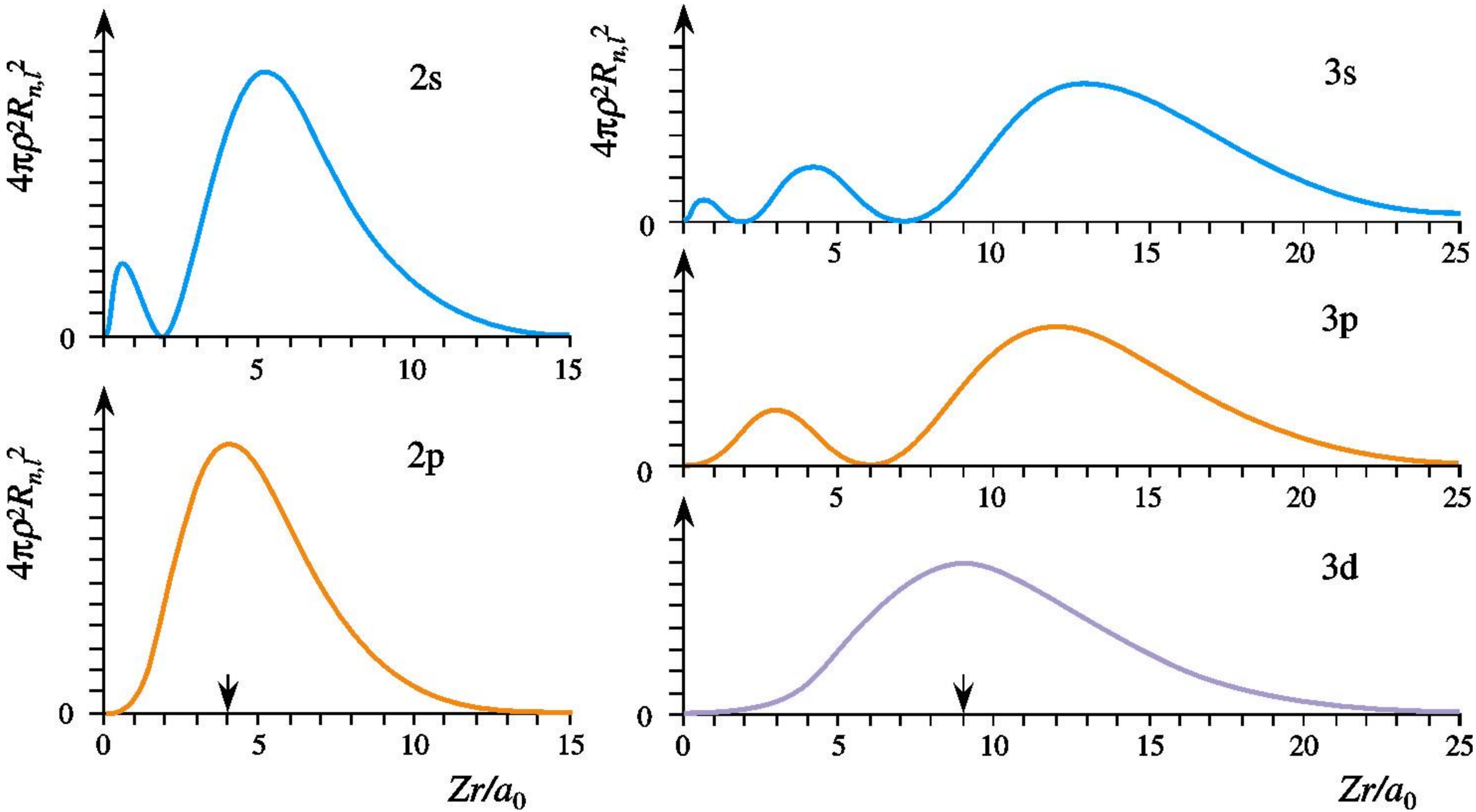
$$\mathrm{d}\tau = \mathrm{d}r \cdot r\,\mathrm{d}\vartheta \cdot r \sin\vartheta\,\mathrm{d}\varphi$$

$$= r^2 \sin\vartheta\,\mathrm{d}\varphi\,\mathrm{d}\vartheta\,\mathrm{d}r$$

$$= r^2 \mathrm{d}r \int_0^{\pi} \sin\vartheta \mathrm{d}\vartheta \int_0^{2\pi} \mathrm{d}\varphi$$

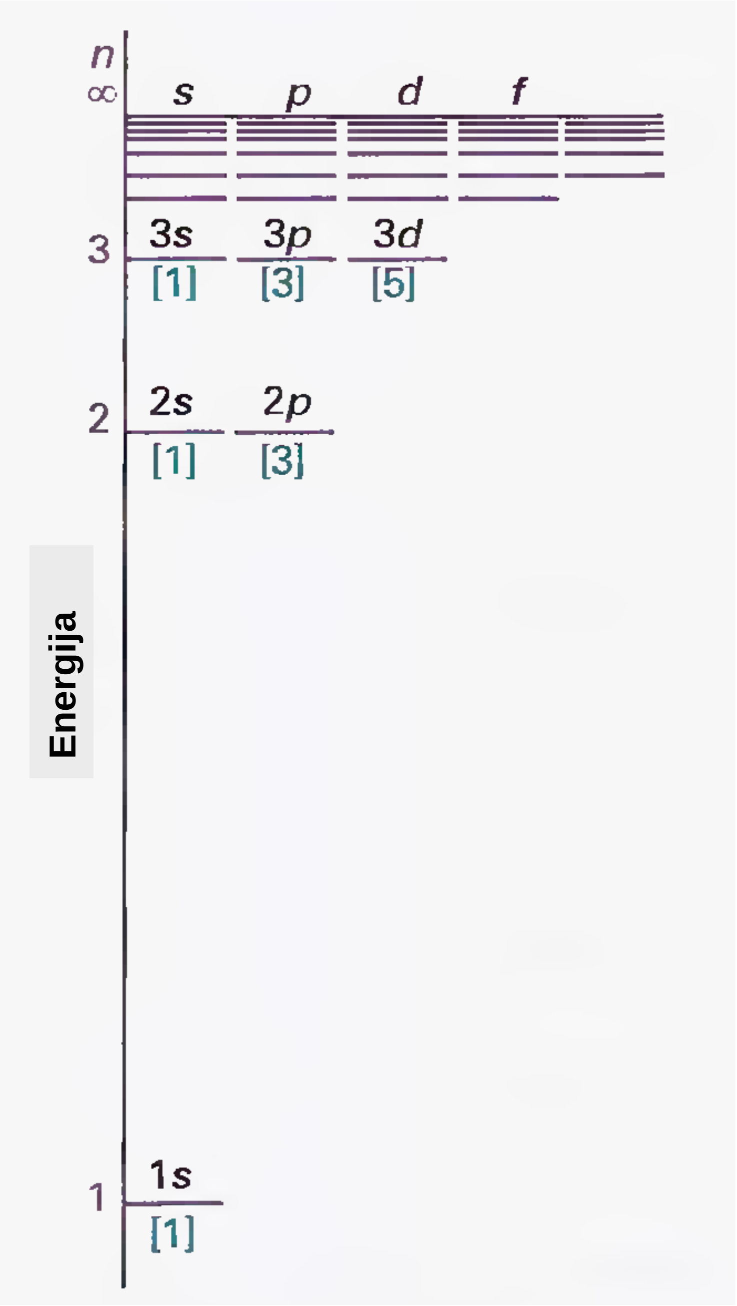
$$= 4\pi r^2 \mathrm{d}r$$

Radijalne gustoće vjerojatnosti



Energija

$$E_e = -hcZ^2 R_\infty \frac{\mu}{m_e} \cdot \frac{1}{n^2}$$



Energija

- za jednoelektronske atome ovisi samo o *n*

- s povećanjem *n* – energetski nivoi su sve bliže $\Rightarrow$ kontinuum

- energija ionizacije E_i

- negativan predznak E $\Rightarrow$ atomi imaju nižu energiju nego elektroni i jezgra na beskonačnoj udaljenosti

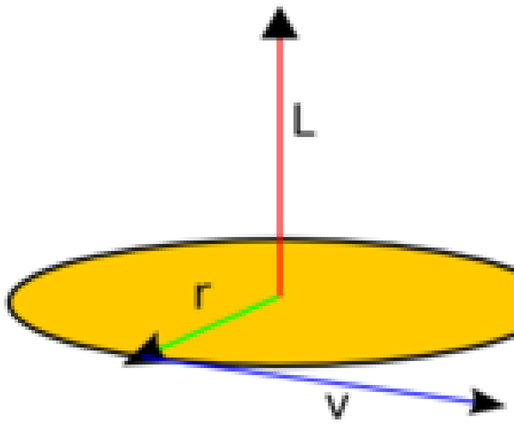
- $n = 1$ $\Rightarrow$ osnovno stanje najniže energije

- energija ovisi i o naboju jezgre Z

$$E_e = -hcZ^2 R_\infty \frac{\mu}{m_e} \cdot \frac{1}{n^2}$$

Kutna količina gibanja

$$\vec{L} = \vec{r} \times m\vec{v}$$



$$L = \sqrt{l(l+1)}\hbar$$

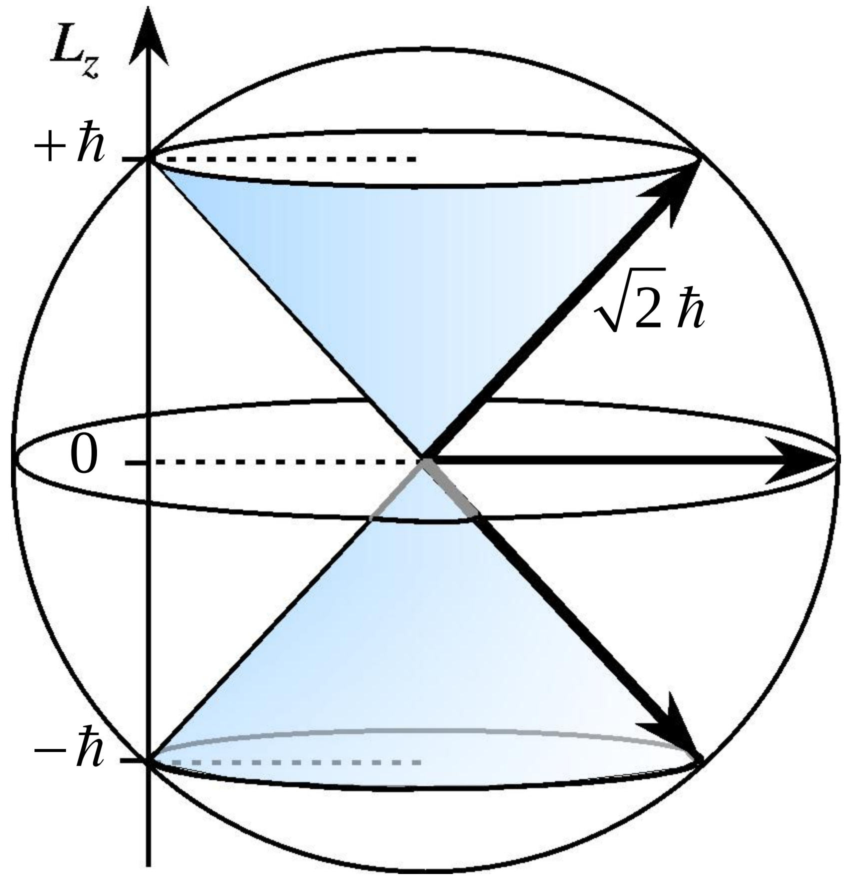
Prostorna kvantizacija

z-komponenta kutne količine gibanja

$l = 1$

$m_l = 0, -1, +1$

$$L_z = m_l \hbar$$



Spin

- 1925. Goudsmit & Uhlenbeck

- klasična slika: vlastita kutna količina gibanja elektrona

- kutna količina gibanja spina

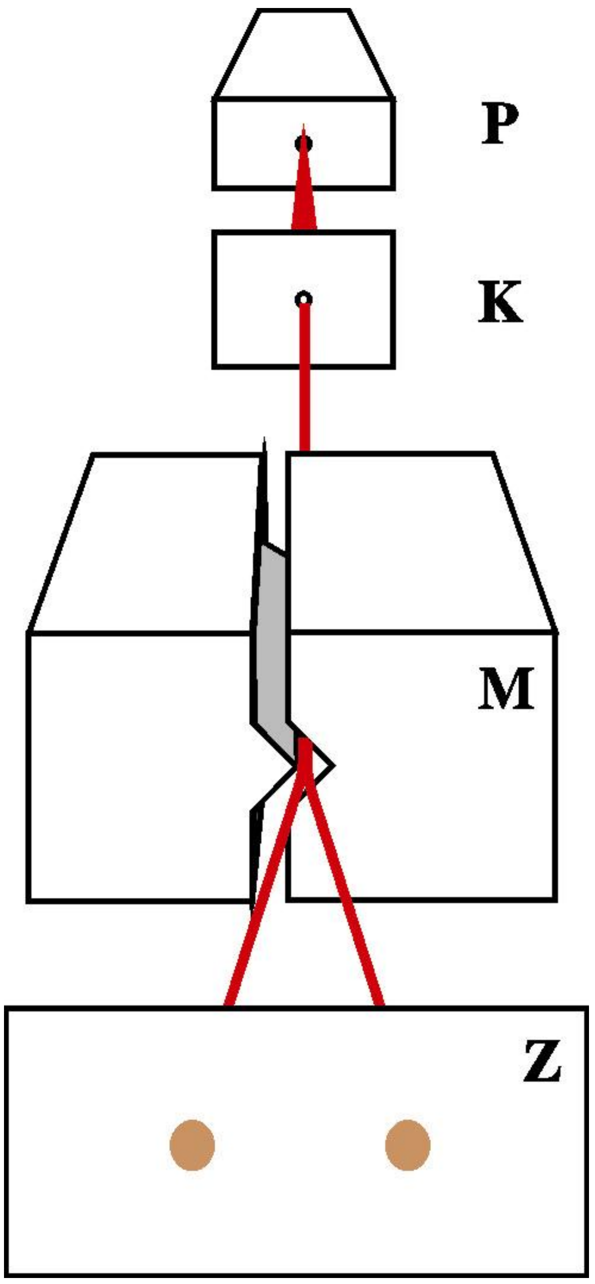
$$S = \sqrt{s(s+1)}\hbar$$

- *s* - kvantni broj spina $s = 1/2$

Stern i Gerlach 1921.

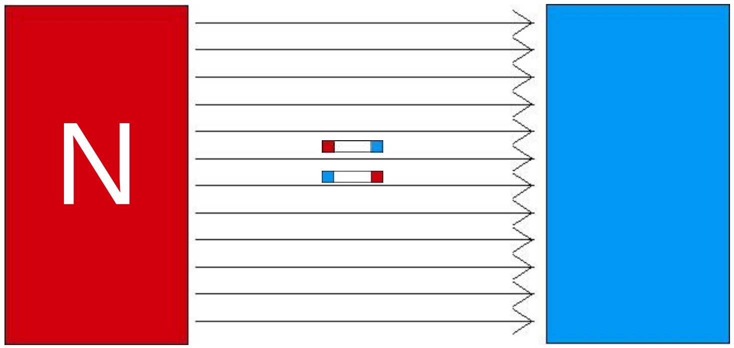
- uski snop atoma srebra kroz nehomogeno magnetsko polje

http://www.youtube.com/watch?v=rg4Fnag4V-E

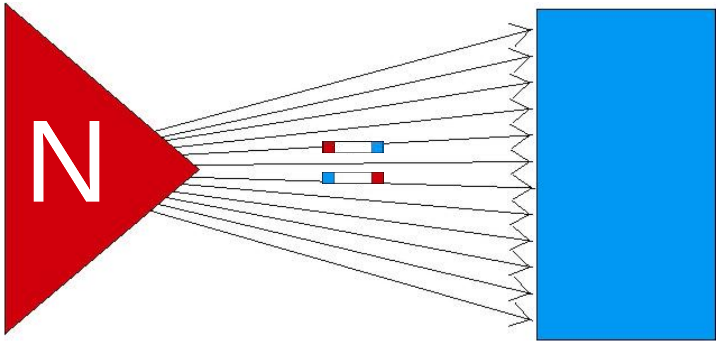


Eksperimentalna provjera prostorna kvantizacije

Homogeno
polje

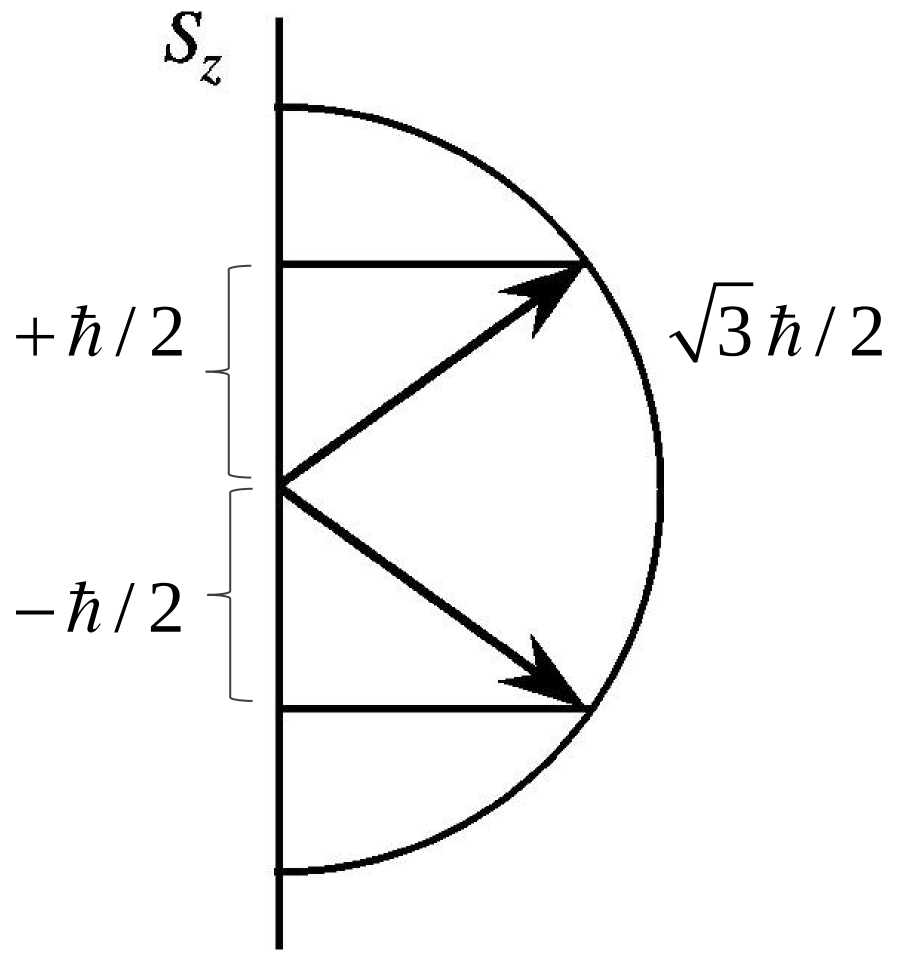


Nehomogeno
polje



Orijentacija u magnetskom polju

$$S_z = m_s \hbar$$



Usporedba Bohrovog modela i rezultata Schrödingerove teorije:

- jednake energije E

- kutne količine gibanja kvantizirane – no razlikuju se

- z-komponenta kutne količine gibanja L_z kvantizirana kod Schrödingove teorije

- egzaktne kružne putanje zamijenjene manje određenim opisom položaja elektrona

- stacionarna stanja u oba modela

Jednoelektronski atom

1. Kako se rješava Schrödingerova jednadžba za atom vodika?
2. Zašto se uvode polarne koordinate?
3. Definirajte polarne koordinate.
4. Kako glasi element prostora u polarnim koordinatama?
5. Koliko kvantih brojeva dobivamo rješavanjem Schrödingerove jednadžbe?
6. O kojim kvantnim brojevima ovisi energija?
7. Kolika je degeneracija razine s kvantnim brojem n?
8. Koje je značenje sporednog kvantnog broja?
9. Koje je značenje magnetskog kvantnog broja?

Atomske orbitale

1. Kako izgleda sinφ u polarnom dijagramu?
2. Što su kugline funkcije i kako izgledaju?
3. U čemu je najbitnija razlika s- i svih ostalih orbitala?
4. Kakav je odnos potencijalne, kinetičke i ukupne energije kod atoma vodika?
5. Po čemu se razlikuju rezultati Bohrova i Schrödingerova modela atoma?
6. Što se ne može objasniti Schrödingerovim modelom atoma?
7. Gdje je najveća elektronska gustoća u osnovnom stanju atoma vodika?
8. Gdje je najveća radijalna gustoća vjerojatnosti za osnovno stanje atoma vodika?

9 Opišite Stern-Gerlachov pokus.

10. Što dokazuje Stern-Gerlachov pokus?
11. Kakav bi bio rezultat pokusa da nema prostorne kvantizacije?

Spin

1. Kako se objašnjava spin?
2. Koja je posljedica postojanja elektronskog spina?
3. Koji su kvantni brojevi vezani uz spin?