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2007 .

53.098, 537.63

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- ., 2007

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III

	5
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1. " : ", , , , -
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3. " ()", ; -
4. " ", , - . ; -

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, . [1], 2.

$$\tilde{v} = R \left(\frac{1}{(n_1 + \mu_1)^2} - \frac{1}{(n_2 + \mu_2)^2} \right), \quad (.1)$$

$$\tilde{v} \equiv 1/\lambda \quad (\quad^{-1}) - \quad , R - \quad , -$$

$$n_2 = (n_1 + 1), (n_1 + 2), (n_1 + 3) \dots \quad \mu_1 = \mu_2 = 0. \quad n_1 \quad -$$

$$(n_1 = 1) \quad \lambda < 185 \quad) \quad -$$

$$R (\quad " \quad -$$

$$(.1) \quad -$$

$$23 \quad , \quad -$$

$$(\quad) -$$

¹ $(n - \Delta), \quad \Delta \quad -$ $\Delta -$ $, \quad n -$ $-$

$$\begin{array}{r}
 , \\
 hc, \\
 , \\
 .
 \end{array}
 \quad
 \begin{array}{r}
 ' \\
 (.1). \\
 hv \\
 ' \\
 - \\
 -
 \end{array}$$

3.1 ИЗ ИСТОРИИ ПЛАНЕТАРНОЙ МОДЕЛИ АТОМА

1666 г., (I.Newton, 1643-1727), [2].
(F.Grimaldi, 1618-1663),
1,
" "
" "
2 " "
1690 г., (Chr.Huygens, 1629-1695) "
" [3].
1 _____
" 1665 "
2 (1894-1952, - , -
- ; -
) " "

XVIII

(G.Leibniz, 1646-1716), . . . (1711-1765), . . .
(L.Euler, 1707-1783). " " -

XVIII -

(P.Bouguer, " " , 1729 .)
(J.Lambert, " " , 1760 .).
1761) . 1758 . (J.Dollond, 1706-
(
) . 1786 .

1801–1803 . . . (Th.Young, 1773 -1829) -

0,42 -

(E.Malus, 1775-1812),
1808 -

(- 52°45') -

(A.Fresnel,1788-1827) 1821 .
 (1818 .).
 (D.Arago,1786-1853),
 (1851 .), "
 " ([3],
 .207).
 (D.Brewster, 1781-1868),
 "
 " .
 I -
 1842 . 60-
 (Ch.Doppler, 1803-1853).
 1860-1865 . . (J.Maxwell,
 1831-1879), -
 ($p = \rho$, $\rho -$),
 1873 .¹
 1824-1887) [4] 1882 . . (G.Kirchhoff,
 (H.Rowland, 1848-1901)
 1883 . , -
 , -

¹ 1899 . . . ,
 (, W.Thomson, 1824-1907) :"
 " ([3]).

,) (
 ,) . -
 , -
 . 1815 .
 . (J.Fraunhofer,1787-1826)
 (), , (
 , , , (
). -
 , -
 . , , -
 (. (Ch.Wheatstone, 1802-
 1875), 1835 .) (.
 (A.Angström, 1814-1874), 1855 .)

, -
 , 80-
 , 800
 , -
 .

1850 . (M.Melloni, 1798-1854)
 " "
 " "1.
 , -
 , -

1

1859-1862
1811-1899),

(R.Bunsen,

(
).

(*rubeus* – , *caesius* –).

1885 . . . (J.Balmer, 1825-1898) ,

(
 $H_\alpha, H_\beta, H_\gamma, H_\delta$),

:

$$\lambda = \lambda_0 \frac{m^2}{m^2 - 4}, \quad m = 3, 4, 5, 6 \dots, \quad \lambda_0 = 3645,7 \text{ \AA} \quad (3.1.1)$$

1869 .

"

...".

Mg ,

" ,

" ,

" .

" .

1

99%

² Mascart E., Comptes Rendus, 1869, v.69, p.337-338.

" (J.Rydberg, 1854-1919) ([5], 2, [1]),

$$\tilde{\nu} = 1/\lambda$$

$$\tilde{\nu} = \tilde{\nu}_0 - R / (m + \mu)^2, \quad (3.1.2)$$

(3.1.2), $\mu = 0, \tilde{\nu}_0 = 1/\lambda_0, R = 4/\lambda_0, R = 109721,6 \text{ cm}^{-1}.$

(3.1.2),

80- 1896 . , 1- , 2- μ

: *principal, diffuse, sharp.*

$$\left\{ \begin{array}{l} 1- \tilde{\nu} = \frac{R}{(1+s)^2} - \frac{R}{(n+p)^2}, \quad n = 2, 3, \dots \\ 2- \tilde{\nu} = \frac{R}{(2+p)^2} - \frac{R}{(n+d)^2}, \quad n = 3, 4, \dots \\ \tilde{\nu} = \frac{R}{(2+p)^2} - \frac{R}{(n+s)^2}, \quad n = 2, 3, \dots \end{array} \right. \quad (3.1.3)$$

1 (G.J.Stoney, 1826-1911) 1871 . $k, k = 2\pi/\lambda.$ (C.Runge, 1856-1927)

,
 ,
 1 , -
 90-
 , -
 , 1907
 (A.Conway, 1875-1950) , 1908
 (W.Ritz, 1878-1909)
 (-), ()

$$\bar{v} = T_1(n_1) - T_2(n_2) \tag{3.1.4}$$

,
 1859
 "

1857-1894). 1889 (H.Hertz, 1887-1902)
 (. . . , 1839-1896). , 1899-1902
 . . . (P.Lenard, 1862-1947) ,

1872 . . . (T.Edison, 1847-1931)
 1879 . . . (J.Stefan, 1835-1893)
 1884 . . . (L.Boltzmann, 1844-1906)

$$W = V\rho(T), \quad p = \rho(T), \quad V$$

$$\begin{aligned} TdS &= dW + pdV = \rho dV + V \frac{d\rho}{dT} dT + \frac{1}{3} \rho dV = \\ &= V \frac{d\rho}{dT} dT + \frac{4}{3} \rho dV. \end{aligned} \quad (3.1.5)$$

([6], 33):

$$\frac{d\rho}{dT} = 4 \frac{\rho}{T}, \quad \rho = a T^4. \quad (3.1.6)$$

1864-1928) . . . 1893 . . . (W.Wien,

$$\rho_v = v^3 f\left(\frac{v}{T}\right) \quad \rho_\lambda = \lambda^{-5} f_1(\lambda T), \quad (3.1.7)$$

.. ρ λ ,
 (3.1.7)

, $\lambda_{\max} T \approx 0,2898$. . .
 1900 . . . (J.Rayleigh 1842-1919)

$$\rho_v = CT, \quad (J.Jeans, 1877-1946) \quad 1905 .$$

$$(3.1.11), \quad . 17.$$

(M. Planck, 1858-1947)

1896 . (.

[7, 8, 9]).

ρ

u :

$$\rho = \frac{8\pi\nu^2}{c^3} u \quad (3.1.8)$$

u .

P

S

, $S = k \cdot \ln P$.

: $\varepsilon_0 = h\nu$.

, $p = \exp(-E/kT)$,

$$u = \frac{\sum_{n=1}^{\infty} n\varepsilon_0 \exp\left(-\frac{n\varepsilon_0}{kT}\right)}{\sum_{n=0}^{\infty} \exp\left(-\frac{n\varepsilon_0}{kT}\right)} = \frac{\varepsilon_0}{\exp\left(\frac{\varepsilon_0}{kT}\right) - 1}, \quad (3.1.9)$$

$$\rho = \frac{8\pi h}{c^3} \frac{\nu^3}{\exp\left(\frac{h\nu}{kT}\right) - 1} \quad (3.1.10)$$

$$h = 6,624 \cdot 10^{-34} \quad . ,$$

$h \rightarrow 0,$

$$\rho = \frac{8\pi v^2}{c^3} kT \quad (3.1.11)$$

" (h v) .

[10]: "

" .

1905 (A.Einstein, 1879-1955),

" [8]. ([5],

1.3)

" $h\nu$.

$$h\nu - h\nu_0 = E_{\max} \quad (3.1.12)$$

¹ (G.N.Lewis, 1875-1946)
1926 .

1905 . , , . -

h

1907 . , -

$$\epsilon_0 = \hbar\omega,$$

$$kT \gg \hbar\omega.$$

$$(3.1.9)$$

() $kT \gg \hbar\omega.$ 1912 .
(P.Debye, 1884-1966),

$$^1 (\sim ^3).$$

1833 . (M.Faraday, 1791-1867).

1826-1911)

1881 . (G.Stoney,

1895 . . (J.Perrin, 1870-1942)

(J.Thomson, 1856-1940)

1837

[5],

1

1901 . , -
 , , -
 , . -
 . (1903 .), -
 10^{-8} , -
 , -
 , -
 . (1904 .) , -
 , -
 . " 1869 . " -
 17 , " -
 [9]. , -
 , . -
 . . -
 , . -
 . (H.Nagaoka, 1865-1950) -
 1903 . " " , -
 . -
 . -
 . . . ¹ (A.Haas, 1884-1941) [5]. -
 1910 . , . -
 . . -
 , . -

¹ (1878-1960), -
 , - , - . -

1911 . . . (E.Rutherford, 1871-1937)

(S.Earenschow)

α -

1

$$\sin^{-4}(\varphi/2),$$

1912 . . .

α -

2

r

1

2

(R.Whiddington) 1911 . . .

[5].

$$\frac{mv^2}{r} = \frac{e^2}{r^2} \quad mv^2 = \frac{e^2}{r}. \quad (3.1.13)$$

W = - -

$$W = -E = \frac{mv^2}{2} - \frac{e^2}{r} = -\frac{e^2}{2r} < 0. \quad (3.1.14)$$

, $v = 2 \sqrt{r}$, -

$$r = \frac{e^2}{2E}, \quad v = \sqrt{\frac{2}{m} \frac{E^{3/2}}{\pi e^2}}, \quad \omega = 2\sqrt{\frac{2}{m} \frac{E^{3/2}}{e^2}} \quad (3.1.15)$$

, -
 , -
 . -
 . -
 , -
 , -

$h/2\pi$. -
 1: -

"1) () -
 , " -

2) , -
 -

¹ [5], 89.

3) $E = h\nu = h \cdot \frac{c}{\lambda} = \frac{hc}{\lambda}$

4) $\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \text{ J}\cdot\text{s} \cdot 3.00 \times 10^8 \text{ m/s}}{1.98 \times 10^{-18} \text{ J}} = 1.02 \times 10^{-7} \text{ m} = 102 \text{ nm}$

5) $\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \text{ J}\cdot\text{s} \cdot 3.00 \times 10^8 \text{ m/s}}{1.98 \times 10^{-18} \text{ J}} = 1.02 \times 10^{-7} \text{ m} = 102 \text{ nm}$

¹ (3.1.14), (3.1.15).

3.2 АТОМ БОРА

1913-

1)

E_i .

2)

$$, hv = \Delta .$$

$$W < 0, \quad Ze, \quad v, \quad r, \quad E = -W > 0. \quad (3.1.13) - (3.1.15)$$

$$mv^2 = \frac{Ze^2}{r}. \quad (3.2.1)$$

$$W = -E = -\frac{Ze^2}{2r} < 0, \quad T = \frac{mv^2}{2} = E, \quad (3.2.2)$$

$$r = \frac{Ze^2}{2E}, \quad \omega = \sqrt{\frac{2}{m}} \frac{E^{3/2}}{\pi Ze^2}. \quad (3.2.3)$$

$$\mu_1 = \mu_2 = 0,$$

$$\tilde{\nu} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right). \quad (3.2.4)$$

$$h\nu = h \bar{\nu} = 1 - 2,$$

$$E_n = \frac{Ry}{n^2}. \quad (3.2.5)$$

$$Ry = Rhc$$

$$h. \quad (3.2.2) - (3.2.5)$$

$$E_n \sim n^{-2}, r_n \sim n^2, \omega_n \sim n^{-3}, v_n \sim n^{-1}, \dots$$

$$M_n = mv_n r_n \sim n.$$

$$M \sim h \quad !$$

$$M_n = nh/2\pi = n\hbar \quad (3.2.6)$$

(4,5 , . 22).

[11, 12],

$$\lambda = 2\pi/k = h/p = \hbar/mv$$

$$mv r = nh/2\pi, \quad 2\pi r/\lambda = n.$$

$$(3.2.2) - (3.2.5)$$

$$(3.2.6),$$

$$v_n = \frac{Ze^2}{M_n} = \frac{Z e^2}{n \hbar}; \quad (3.2.7)$$

$$E_n = \frac{Z^2 m e^4}{2\hbar^2 n^2} = Ry \frac{Z^2}{n^2}; \quad Ry = \frac{m e^4}{2\hbar^2} \approx 13,6; \quad (3.2.8)$$

$$r_n = \frac{\hbar^2 n^2}{Z m e^2} = \frac{n^2}{Z} a_B ; \quad a_B = \frac{\hbar^2}{m e^2} \approx 0,0529 \quad ; \quad (3.2.9)$$

$$\omega_n = \frac{m Z^2 e^4}{M_n^3} = \frac{Z^2}{n^3} \frac{m e^4}{\hbar^3} . \quad (3.2.10)$$

$$Z = 1 .$$

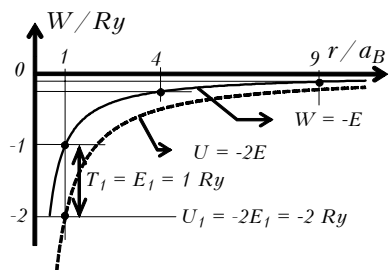
$$(3.2.7) - (3.2.10) \quad ,$$

3.2.1

(3.2.1),
(3.2.8), (3.2.9),

a_B ,

3.2.1



$n = 1 .$

$1 Ry = 13,6$,

)

$Li^{+2}, Be^{+3} \dots - Z^2$
 $a_B \approx 0,0529 \quad Z$

3.2.1

– (3.2.10)

μ .

$$4m$$

(3.2.8)

$$\frac{1}{\mu_H} = \frac{1}{m} + \frac{1}{M},$$

$$\frac{1}{\mu_{He}} = \frac{1}{m} + \frac{1}{4M},$$

(3.2.11)

$$\frac{\mu_{He}}{\mu_H} = 1 + \frac{3}{4} \frac{m}{M+m}.$$

$$R_H = 109677,576 \text{ }^{-1}; \quad R_{He^3} = 109717,345 \text{ }^{-1};$$

$$R_D = 109707,419 \text{ }^{-1}; \quad R_{He^4} = 109722,267 \text{ }^{-1}. \quad (3.2.12)$$

$$R_\infty = 109737 \text{ cm}^{-1}$$

$$(3.2.11) \quad (3.2.12) \quad , \quad M \approx 1841m$$

$$M/m = 1837,$$

3.3 СПЕКТРЫ ВОДОРОДОПОДОБНЫХ АТОМОВ

..., () -
 (" ") , -
 " "

3.3.1.

(3.2.8) , " + "

$$h\nu = E_n - E_m = RZ^2 \left(\frac{1}{n^2} - \frac{1}{m^2} \right), \quad (3.3.1)$$

$$\tilde{\nu} = \frac{R \cdot Z^2}{hc} \left(\frac{1}{n^2} - \frac{1}{m^2} \right) = RZ^2 \left(\frac{1}{n^2} - \frac{1}{m^2} \right). \quad (3.3.2)$$

(3.2.12).

$$3/4, 8/9 \dots (n^2-1)/n^2$$

$$3/4 R \approx 10,2 \text{ }^{-1},$$

$$+ \approx 40,8$$

$$n = 2, 3 \dots$$

$$121,5; 102,5; 97,2 \dots$$

$$91,125$$

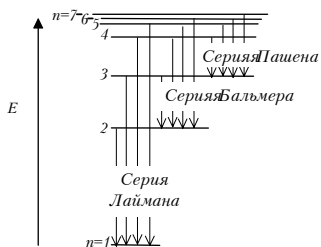
()

1

$$kT \approx 0,025 \text{ }^{-1}, 408$$

$$\approx 6,4 \cdot 10^{-178}$$

$h\nu > 13,6$



3.3.1.

3.3.1
4-
3-
 $n = 2,$

$(n = 1)$

$(n \geq 3)$

$L_\alpha, L_\beta, L_\gamma, L_\delta -$
 $\alpha -$
 $(m \rightarrow \infty)$

$H_\alpha, H_\beta, H_\gamma, H_\delta -$
 $(3.3.1),$

[1]),

3.3.2.

s, p, d.

(3.1.3)

s, p, d.

3.3.2.1. Щелочные металлы. Квантовый дефект

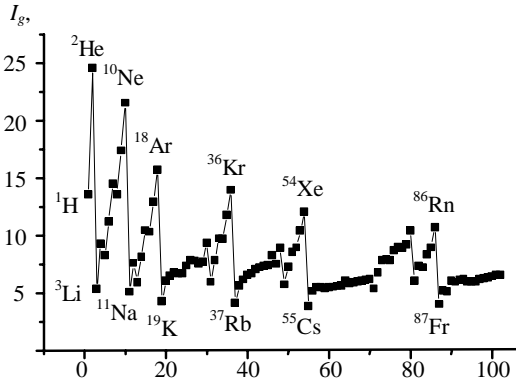
E
(I_g) [13]

(3.3.2).

18, 18, 32.

8, 8,

$2n^2$).



3.3.2.

[13].

(3.1.3).

- 2 -

$$T_{ns} = \frac{R}{(n+s)^2}, \quad n = 1, 2, 3, \dots \quad (3.3.3)$$

(3.1.3)

$$n = 2 \quad T_{np} \quad n = 3 \quad T_{nd}$$

(3.3.3)

$$n, \quad (3.2.8), (3.2.9) \quad (24)$$

$$T_{ns} = \frac{e^2}{4\pi\epsilon_0} \frac{1}{n^2} \left(\frac{Z - \delta}{n} \right)^2 \quad (3.2.8)$$

$$= 0,0529 \quad n = 1, \quad U = E/r \quad (3.3.3)$$

Li → Na → K → Rb → Cs → Fr.

$$(n + s)^2 = (n_s - \Delta_s)^2, \quad n_s - \Delta_s > 1. \quad (3.1.3)$$

$$T_{ns} = \frac{Ry}{(n + s)^2} = \frac{mE^4}{2\hbar^2} \frac{1}{(n_s - \Delta_s)^2} = \frac{mE^4}{2\hbar^2} \frac{(Z - \delta)^2}{n_s^2}, \quad (3.3.4)$$

Δ_s δ n_s 3.3.1.

n . (3.2.8),

$$(Z-\delta) > 1,$$

" $\Delta_s,$

3.3.1

Z		n_s		$Ry/n_s^2,$	$I,$	Δ_s	$Z-\delta$
3	Li	2	2	3,4	5,39	0,41	1,26
11	Na	3	2+8=10	1,51	5,14	1,37	1,84
19	K	4	2+8+8=18	0,85	4,34	2,23	2,26
37	Rb	5	2+8+18+8=36	0,54	4,18	3,20	2,78
55	Cs	6	2+8+18+18+8=54	0,38	3,89	4,13	3,2

[1, 6, 11, 12],

3.3.2.2. Квантовомеханическая трактовка задачи об атоме водорода

$$\Delta x \Delta p \geq \hbar, \quad \Delta E \Delta t \geq \hbar, \quad (3.3.5)$$

$$10^{-13} \quad (3.3.5),$$

$$\Delta p \geq \frac{\hbar}{\Delta x} \approx \frac{1,055 \cdot 10^{-34}}{10^{-15}} \approx 10^{-19} \quad \cdot / , \approx 10^{-14} \quad \cdot / ,$$

$$\Delta E = \frac{\Delta p^2}{2m_E} = \frac{10^{-28}}{2 \cdot 9,1 \cdot 10^{-28}} \approx 0,06 \quad 3,5 \cdot 10^{10} \quad ,$$

.. 9

$$\hat{p} = -i\hbar\nabla, \quad \hat{p} = -i\hbar\nabla$$

$$\hat{E}_{\text{кин}} = \frac{\hat{p}^2}{2m_E} = -\frac{\hbar^2}{2m_E} \nabla^2.$$

$$\hat{H} = -\frac{\hbar^2}{2m_E} \nabla^2 - \frac{ZE^2}{|\mathbf{r}|}. \quad (3.3.6)$$

ψ^{\circledast}

$$\hat{H}\psi(\mathbf{r}) = E\psi(\mathbf{r}), \quad (3.3.7)$$

(3.3.7)

: $x = r \cdot \sin\theta \cdot \cos\varphi$; $y = r \cdot \sin\theta \cdot \sin\varphi$; $z = r \cdot \cos\theta$.

$$\nabla^2 = \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial}{\partial r} \right) + \frac{1}{r^2 \sin\theta} \frac{\partial}{\partial \theta} \left(\sin\theta \frac{\partial}{\partial \theta} \right) + \frac{1}{r^2 \sin^2\theta} \frac{\partial^2}{\partial \varphi^2}, \quad (3.3.8)$$

$$\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \Psi}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \Psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \Psi}{\partial \varphi^2} + \frac{2m_E}{\hbar^2} \left(E + \frac{ZE^2}{r} \right) \Psi = 0 \quad (3.3.9)$$

$$\Psi(r, \theta, \varphi) \quad -$$

$$\Psi(r, \theta, \varphi) = R(r) \cdot \Theta(\theta) \cdot \Phi(\varphi), \quad (3.3.10)$$

[13]:

$$R_{nl}(\rho) = \exp(-\rho/2) \cdot \rho^l \cdot L_{n+l}^{2l+1}(\rho), \quad (3.3.11)$$

$$\Theta_{lm}(\theta) = \left[\frac{(2l+1)(l-|m|)!}{2(l+|m|)!} \right]^{1/2} P_l^{|m|}(\cos \theta), \quad (3.3.12)$$

$$\Phi_m(\varphi) = \frac{1}{\sqrt{2\pi}} \exp(\pm im\varphi). \quad (3.3.13)$$

$$\rho \equiv \frac{2Z}{nE_B} r, \quad (3.3.14)$$

$$Z- \quad , n- \quad , - \quad . \quad (3.3.7)$$

$$l = 0, 1, \dots (n-1), \quad n = 1, 2, \dots, -$$

$$-l \leq m \leq l. \quad (3.3.11) \quad (3.3.12) \quad L_{n+l}^{2l+1}(\rho) \quad P_l^{|m|}(\cos \theta) -$$

$$L_n^k(\rho) = \frac{d^k}{d\rho^k} \left\{ e^\rho \frac{d^n}{d\rho^n} (\rho^n e^{-\rho}) \right\},$$

:

$$P_l^{|m|}(x) = \frac{1}{2^l l!} [1-x^2]^{m/2} \frac{d^{l+|m|}}{dx^{l+|m|}} [x^2-1]^l.$$

:

$$Y_{lm}(\theta, \varphi) = \Theta_{lm}(\theta)\Phi_m(\varphi) = \left[\frac{(2l+1)(l-|m|)!}{4\pi(l+|m|)!} \right]^{1/2} P_l^{|m|}(\cos\theta)e^{im\varphi} \quad (3.3.15)$$

Y_{lm}

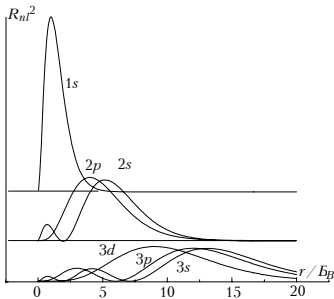
$$l = m = 0 \quad Y_{00} = (1/4\pi)^{1/2},$$

l

$$-l \leq m \leq l$$

[12]

$l, m -$



(3.2.9).

3.3.3

$R_{nl}(\rho),$

3.3.2

$R_{nl}^2(r/a_B), \dots$

$l = 0, 1, 2, 3, \dots$
 : sharp, principal, diffuse, fundamental. $0 \leq l \leq (n-1)$,
 : 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f ...

1. $R_{nl}(R)$ $(n-l-1)$. 1s, 2p, 3d, 4f...

2. $\int r |R_{nl}(r)|^2 dr$ -
 $\int r^{-1} |R_{nl}(r)|^2 dr$,
 l -
 (3.2.8), (3.2.9) -
 $a_B n^2$, $- Ry/n^2$ -
 $n > 1$, ..

$(2l+1)$,
 $1, 4, 9 \dots n^2$,

$(2n^2)$,

1, . 3.3.1 . 3.2.

3.3.2

1 , K, 3- 4s 18-
 3d. 4d, 4f ...
 5-

$a_B n^2 -$

1s-

() .

2s- 2p-

. 3.3.2,

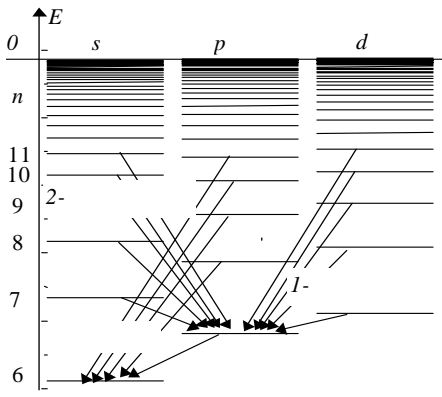
(3.1.2),
 n

s-, p- d-

. (3.1.3).

n s, p, d (3.1.3)

[1].



. 3.3.4.

Cs

1- 2-

Cs⁺.

3,89

Cs,

— 1,38

$\pm 1.$

$$, \quad (3.1.3)$$

$ns.$ Cs – 6s, . 3.3.3.

$$- \quad 6,$$

, - 7, 8 ...

7s... .).

6s (

- s- . 1-

- , d- , 2-

. 31.

3.3.2.3. Ридберговские серии в молекулярных спектрах

$n = 10$, n^2 , . (3.2.9).

5 ,

$$\approx 0,14$$

(3.2.9)

5 .

3.4 СВЕРХТОНКАЯ СТРУКТУРА АТОМНЫХ СПЕКТРОВ

3.4.1.

$$\vec{\mu} = \frac{1}{2c} \frac{E}{m} \vec{P}. \quad (3.4.1)$$

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

$$\mu_l = \mu_0 \sqrt{l(l+1)}, \quad \mu_0 = \frac{\hbar}{2c} \frac{E}{m}.$$

$$\vec{\mu}_s = \frac{1}{2c} \frac{E}{m} \vec{P}_s. \quad (3.4.2)$$

$$P_s = \hbar \sqrt{s(s+1)}, \quad \mu_s = 2\mu_0 \sqrt{s(s+1)}$$

$$P_J = \hbar \sqrt{J(J+1)},$$

$$\mu_J = g(J) \frac{1}{2c} \frac{E}{m} P_J, \quad (3.4.3)$$

$g(J)$ -

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}. \quad (3.4.4)$$

(3.4.3)

μ_I

P_I

$$\mu_I = g(I) \frac{1}{2c} \frac{E}{M} P_I, \quad (3.4.5)$$

$\frac{E}{M}$ -

$g(I)$ -

$g(I) = 5,585.$

$$\mu = \frac{\hbar}{2c} \frac{E}{M} \quad (3.4.6)$$

$$\frac{\mu}{\mu_0} = \frac{m}{M} = \frac{1}{1836}, \dots$$

$$P_I = \hbar \sqrt{I(I+1)} \quad (3.4.7)$$

$$(3.4.5) - (3.4.7),$$

$$\mu_I = g(I)\mu \sqrt{I(I+1)}. \quad (3.4.8)$$

m_I
 $I.$

$$\mu_I,$$

$$\mu_{I_z} = m_I g(I) \mu,$$

$$m_I = I, (I-1), \dots, -$$

$$I g(I) \mu.$$

$$(3.4.8)$$

$$\mu_I = I g(I) \mu. \quad (3.4.8)$$

$$I=1/2 \quad g(I) = 5,585,$$

$$2,7927 \mu.$$

$$\vec{P}_F = \vec{P}_I + \vec{P}_J.$$

$$\delta W = \mu_I H(0) \cos(\vec{P}_I, \vec{P}_J). \quad (3.4.9)$$

(0)-

(3.4.9)

$$\delta W = \frac{A}{2} [F(F+1) - I(I+1) - J(J+1)], \quad (3.4.10)$$

A -

$$A = \frac{\mu_l H(0)}{\sqrt{I(I+1)J(J+1)}}.$$

I+J-1, ..., |I-J|.

$$\delta \tilde{v} = \frac{\delta W_{F+1} - \delta W_F}{hc} = A \frac{F+1}{hc}.$$

$$A = \frac{2l(l+1)}{j(j+1)} \overline{\left(\frac{1}{r^3}\right)} \cdot \mu_l \mu_0. \quad (3.4.11)$$

$$\overline{\left(\frac{1}{r^3}\right)}$$

$$\overline{\left(\frac{1}{r^3}\right)} = \frac{Z^3}{E_0^3 n^3 (l+1/2) l(l+1)} \quad (3.4.12)$$

$$E_0 = \frac{\hbar^2}{mE^2}.$$

(3.4.11), (3.4.12)

$$A = \frac{hcR\alpha^2 Z^3}{n^3(l+1/2)j(j+1)} \frac{g(I)\mu}{\mu_0}, \quad (3.4.11)$$

$$\left(\frac{1}{r^3}\right) \quad (3.4.12),$$

$$A = \frac{hcR\alpha^2 Z^3}{n^3(l+1/2)j(j+1)} \frac{g(I)\mu}{\mu_0}, \quad (3.4.13)$$

$$R - \alpha = E^2/\hbar c$$

A

$$A = \frac{hcR\alpha^2 Z_i Z_B^2}{n^{*3} (l+1/2) \cdot j(j+1)} \frac{g(I)}{1836} \quad (3.4.14)$$

Z_a

, Z_i

, n^{*-}

s-

$$l=0, j=1/2, Z_a=1 \quad Z_i$$

$$A = \frac{8hcR\alpha^2 Z Z_B^2}{3n^{*3}} \frac{g(I)}{1836} \quad (3.4.15)$$

(3.4.15)

$$g(I)$$

(3.4.8)

$I,$

μ

μ_I

3.5 ЛАБОРАТОРНАЯ РАБОТА "Постоянная Ридберга"

$$\tilde{\nu} = R \left(\frac{1}{2^2} - \frac{1}{n^2} \right).$$

$$\tilde{\nu} = \frac{R}{4} - \frac{R}{n^2}. \quad (3.5.1)$$

$$\frac{1}{n^2}, \quad R/4, \quad -R.$$

3.5.1. ()

$$(). \quad ()$$

$$\lambda_x = \lambda_2 + (\lambda_1 - \lambda_2) \frac{n_x - n_2}{n_1 - n_2} \quad (3.5.2)$$

$$\lambda_x, n_x$$

$$; \lambda_1, \lambda_2, n_1, n_2 -$$

$$:$$

$$\bar{v} = \bar{v}_1 + (\bar{v}_2 - \bar{v}_1) \frac{n_x - n_1}{n_2 - n_1}. \quad (3.5.3)$$

$$(3.5.2) \quad , \quad \lambda_1 > \lambda_2,$$

$$(3.5.3) \quad (\quad).$$

$$(3.5.2)$$

$$\lambda = \lambda_0 + \frac{A}{n - n_0}, \quad (3.5.4)$$

$$\lambda_0, n_0, A - \quad (\quad -$$

$$).$$

$$v, \quad (3.5.3)$$

$$\lambda = 1/v,$$

$$v = v_0 + c / (x - x_0), \quad (3.5.5)$$

$$v_0, x_0, c -$$

$$v_0, x_0, c, \quad (3.5.5),$$

$$v_1, v_2, v_3, \quad x_1, x_2,$$

$x_3,$

:

$$x_0 = x_1 + (\tilde{\nu}_3 - \tilde{\nu}_2) \frac{(x_2 - x_1)(x_3 - x_1)}{(\tilde{\nu}_3 - \tilde{\nu}_1)(x_2 - x_1) - (\tilde{\nu}_2 - \tilde{\nu}_1)(x_3 - x_1)}$$

$$c = (\tilde{\nu}_2 - \tilde{\nu}_1) \frac{(x_1 - x_0)(x_2 - x_0)}{x_2 - x_1}$$

$$\tilde{\nu}_0 = \tilde{\nu}_1 - \frac{c}{x_1 - x_0} \tag{3.5.6}$$

$$, \quad , \quad v_1, \quad x_1 = 0 \tag{3.5.6}$$

:

$$x_0 = (\tilde{\nu}_3 - \tilde{\nu}_2) \frac{x_2 x_3}{(\tilde{\nu}_3 - \tilde{\nu}_1)x_2 - (\tilde{\nu}_2 - \tilde{\nu}_1)x_3}$$

$$c = (\tilde{\nu}_2 - \tilde{\nu}_1) \frac{(x_1 - x_0)x_0}{x_2}$$

$$\tilde{\nu}_0 = \tilde{\nu}_1 + \frac{c}{x_0} \tag{3.5.7}$$

$$\tilde{\nu}_0, x_0, c \tag{3.5.5},$$

$$\tilde{\nu}_1, \tilde{\nu}_3.$$

$$(3.5.4)$$

$$(3.5.6) \quad (3.5.7)$$

$$x_0, c, v_0, n_0, A, \lambda_0, v_i, \lambda_i.$$

100

3.5.2.

2.5.5).
1. ()
2. ()

1.

2.

3.

4.

(... $\lambda=491,6$).

5.

6.

- 7.
- 8. $H_\alpha, H_\beta, H_\gamma, H_\delta$
- 9.

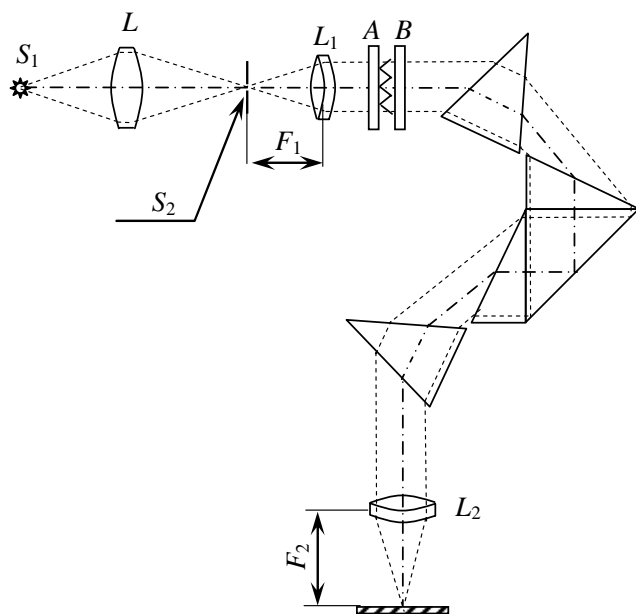
3.5.3.

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

3.6 ЛАБОРАТОРНАЯ РАБОТА "Спектроскопическое определение ядерных моментов" (СТС).

3.6.1.

(. . . 3.6.1).



. 3.6.1

-51

- 51 .

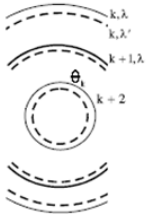
$$\cos \frac{\theta_{\mathcal{I}}}{2} = \mathcal{I} \frac{\lambda}{2t}, \quad (3.6.1)$$

\mathcal{I} -

$\lambda \quad \lambda'$,

() ,

. 3.6.2



. 3.6.2.

d

$$d = \theta \times F_2,$$

F_2 -

$$\cos \frac{\theta_{J'}}{2} \approx 1 - \frac{\theta_{J'}^2}{8} \quad \lambda$$

λ'

$$\theta_{J'}^2 = 8 - J' \frac{4\lambda}{t}, \quad \theta_{J'}^2 = 8 - J' \frac{4\lambda'}{t} \quad (3.6.2)$$

$$d\lambda = \lambda' - \lambda = \frac{t}{4J'} (\theta_{J'}^2 - \theta_{J'}'^2). \quad (3.6.3)$$

$(J+1)$

$$\theta_{J+1}^2 = 8 - (J+1) \frac{4\lambda}{t}. \quad (3.6.4)$$

(3.6.2) (3.6.4) :

$$\frac{4\lambda}{t} = \theta_{J'}^2 - \theta_{J+1}^2. \quad (3.6.5)$$

t (3.6.3)-(3.6.5) :

$$d\lambda = \frac{\lambda}{J} \frac{\theta_{J'}^2 - \theta_{J'}'^2}{\theta_{J'}^2 - \theta_{J+1}^2}. \quad (3.6.6)$$

$$J = \frac{2t}{\lambda} \quad (3.6.1), \quad (3.6.6) \quad :$$

$$d\lambda = \frac{\lambda^2}{2t} \frac{\theta_{J'}^2 - \theta_{J'}'^2}{\theta_{J'}^2 - \theta_{J+1}^2}. \quad (3.6.7)$$

$$\tilde{v} = \frac{1}{\lambda}, \quad :$$

$$d\tilde{\nu} = \frac{1}{2t} \frac{\theta_{J'}^2 - \theta_{J'}'^2}{\theta_{J'}^2 - \theta_{J'+1}^2} \quad (3.6.8)$$

$$d\tilde{\nu} = \frac{1}{2t} \frac{d_{J'}^2 - d_{J'}'^2}{d_{J'}^2 - d_{J'+1}^2} \quad (3.6.9)$$

$d\tilde{\nu}$

$d\tilde{\nu}$

(3.6.9),

3.6.2.

$5^2 S_{1/2}$

Rb^{87}

$6^2 P_{1/2} - 5^2 S_{1/2}$

$6^2 P_{3/2} - 5^2 S_{1/2}$

$5^2 S_{1/2}$

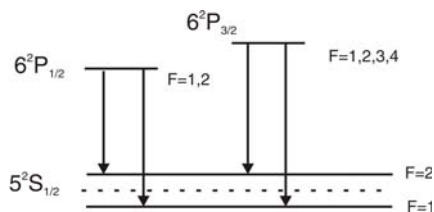
. 3.6.3.

$6^2 P_{1/2}$

$6^2 P_{3/2}$

(

?).



. 3.6.3

Rb.

$$g(I) \quad Rb^{87}, \quad (3.4.13), \quad 44, \quad d\tilde{\nu} \quad -$$

$$\mu_I/\mu_{\mathcal{R}0} \quad -$$

(3.4.13): $\alpha^2 = (1/137)^2 = 5,324 \cdot 10^{-5}$, $n^* = 1,80$,
 $Z = 37, Z = 1, R = 109737^{-1}, I = 3/2, J = 1/2$.

3.6.3.

$$-51, \quad -$$

$$-51-30. \quad -$$

$$6 \quad 6 \quad -$$

$$-1. \quad -$$

$$1) \quad -$$

$$2) \quad -$$

$$3) \quad -$$

$$4) \quad Rb^{87}. \quad -$$

$$-12 \quad -$$

$$5) \quad d\tilde{\nu} \quad Rb^{87}. \quad -$$

$$\mu_I/\mu_{\mathcal{R}0} \quad Rb^{87}. \quad -$$

3.6.4.

- 1) .
- 2) -

- 3) $d\tilde{\nu}$
- 4) Rb^{87} .
- 5) $g(I)$.
- 6) $\mu_I/\mu_{\pi 0}$ Rb^{87} .

3.7 ЛАБОРАТОРНАЯ РАБОТА "Магнитное расщепление спектральных линий" (Эффект Зеемана)

3.7.1.

В магнитном поле энергетические уровни атома расщепляются. Энергия уровня J с магнитным квантовым числом M определяется формулой:

$$E_{JM} = E_J + M g \mu_B B$$

где E_J — энергия уровня без поля, μ_B — магнетон Бора, B — индукция магнитного поля. Коэффициент g называется фактором Ланде. Для уровня с орбитальным квантовым числом L и спиновым квантовым числом S фактор Ланде вычисляется по формуле:

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)} \quad (3.7.1)$$

где S — спиновое квантовое число, L — орбитальное квантовое число, J — суммарное квантовое число. При $S = 0$ и $J = L$ фактор Ланде равен $g = 1$.

$$\Delta W = M_j g \mu_0 H, \quad (3.7.2)$$

$$M_j = -J, -J+1, \dots, J-1, J, \quad (3.7.3)$$

$$\Delta W = M_j \mu_0 H \quad (3.7.3)$$

$$M_j = 0, \pm 1, \dots, \pm J$$

$$\Delta v = \left(\frac{E}{m} \right) \frac{H}{4\pi c}, \dots$$

$$\Delta v = \left(\frac{e}{m} \right) \frac{H}{4\pi c} \quad (3.7.4)$$

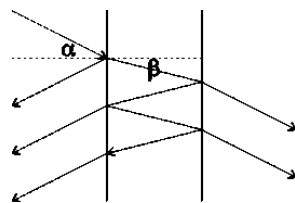
$$H - \dots; e/m - \dots \quad (3.7.3)$$

$$e/m = c, \quad (3.7.3)$$

$$\Delta\lambda = \frac{\lambda^2}{c} \left(\frac{E}{m} \right) \frac{H}{4\pi}$$

$$\frac{6000}{0,1} \Delta\lambda$$

3.7.2.

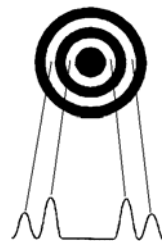


3.7.1.

$$D = 2t\sqrt{n^2 - \sin^2 \alpha} = 2tn \cos \beta$$

t — , n —

$$\frac{D}{\lambda} = \mathcal{M}, \quad \mathcal{M} -$$



3.7.2

$F \cdot \text{tg} \quad F -$

(\mathcal{J} D), (3.7.2).

$k-$

$$\mathcal{J} = \frac{D}{\lambda} = 2 \frac{t}{\lambda} \sqrt{n^2 - \sin^2 \alpha} \quad (3.7.6)$$

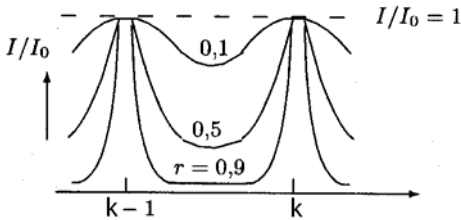
(-)

$$\mathcal{J}_1 = 2 \frac{t}{\lambda} \sqrt{n^2 - \sin^2 \alpha_1},$$

$$\mathcal{J}_2 = (\mathcal{J}_1 - 1),$$

$$\mathcal{J}_3 = (\mathcal{J}_1 - 2) \dots$$

$$\mathcal{J} = \mathcal{J}_l - (P - 1).$$



r (3.7.3).

3.7.3.

\mathcal{J}_a

$r.$

$$J = 2 \frac{t}{\lambda} \sqrt{n^2 - \sin^2 \alpha} \quad (3.7.6)$$

$$J = 2 \frac{t}{\lambda_1} \sqrt{n^2 - \sin^2 \alpha'} \quad (3.7.7)$$

$$J_p = \frac{d}{2t \mu \cos \alpha} = 1 \quad (3.7.8)$$

$$\Delta \beta = -\frac{\lambda}{2tn \sin \beta} = \frac{\lambda}{2t \sin \alpha}, \quad d\beta = -\frac{J d\lambda}{2tn \sin \beta} = \frac{J d\lambda}{2t \sin \alpha} \quad (3.7.7)$$

$$\sin \alpha = n \sin \beta, \quad d\alpha = n \frac{\cos \beta}{\cos \alpha} d\beta$$

$$\Delta \alpha = -n \frac{\cos \beta}{\cos \alpha} \frac{\lambda}{2t \sin \alpha}, \quad d\alpha = -n \frac{\cos \beta}{\cos \alpha} \frac{J d\lambda}{2t \sin \alpha} \quad (3.7.8)$$

$$d < \lambda/2, \quad \lambda/2, \quad \dots$$

$$d > \lambda/2$$

$$d < \lambda/2$$

$$d\lambda < \lambda/J$$

$$\lambda/J = \Delta\lambda$$

$$d\lambda = \Delta\lambda/2$$

$$J = \frac{2tn \cdot \cos\beta}{\lambda}$$

$$\cos\beta = 1$$

$$J = \frac{2tn}{\lambda}$$

$$t = 0.5 \quad n = 1.5$$

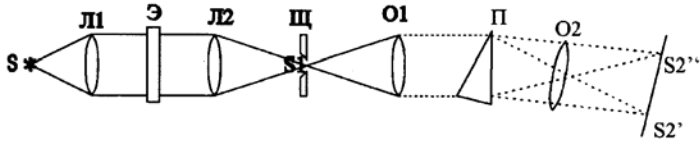
$$= 5,5 \cdot 10^{-5}$$

$$d < 0.1$$

3.6.1.

. 3.7.4

S 1, 1 -



. 3.7.4

1

2,

2

S_1 .

1

2

2

(S_1)

2-3

2-3

3.7.3.

, ()

3

, ±

$$\Delta v = \frac{E H}{m 4\pi c}$$

- , , -

+ (),

(H),

P- P + 1-

P-

(P + 1)-

(P + 1)-

P-

, d = /2,

-

-

-

-

-

-

-

-

$(P + 1)$ - , P - $d = 1/2$,
 ,
 ,
 P - $(P + 1)$ -
 $d = (P + 1)$ - P -
 $(P - 1)$ - P -
 $(P + 1)$ - , $(P + 1)$ -
 $P + 2$ - P - , $d = 3 \cdot 1/2$. . .
 ,
 H_2, H_3, H_5 . . . $d = 1/2, d = 3 \cdot 1/2, d = 5 \cdot 1/2$
 ,
 H_2, H_4, H_6 . . . ,

3.7.3.1. Практические указания

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(P + 1)- (-),

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H.

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3.7.4.

- 1)
- 2) *d* .
- 3)

3.7.4.1. Условные обозначения:

— ;
v — ;
e/m — (CGSM);
— ;
t — - ;
D — ;
n — - ;
Л — ();
— ;
F — ;
G — ;
— ;
— - .

-
- 1 , 1963.
 - 2 , 1974.
 - 3 XVIII , 1970.
 - 4 , 1983.
 - 5 , 1985.
 - 6 , 1965.
 - 7 , 1977.
 - 8 , 1977.
 - 9 , 1981.
 - 10 , 1990.
 - 11 (.), , 1963.
 - 12 2- , 1979.
 - 13 , 1991. 1232
 - 14 - , 1936.