UVOD U KVANTNU TEORIJU

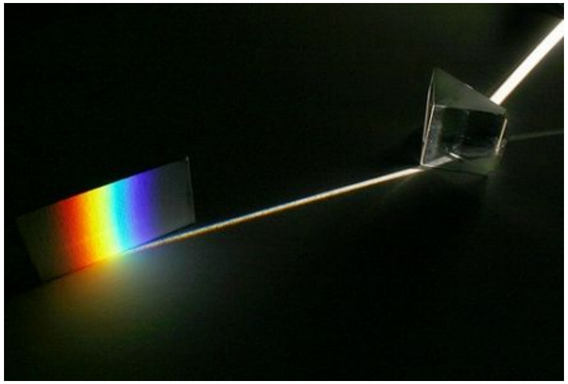
1.) FOTOELEKTRIČKI EFEKT

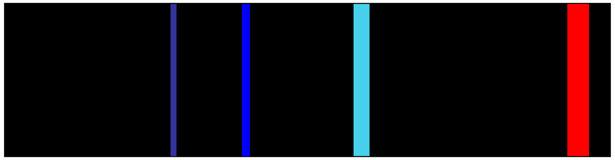
2.) LINIJSKI SPEKTRI ATOMA

3.) BOHROV MODEL ATOMA

4.) CRNO TIJELO

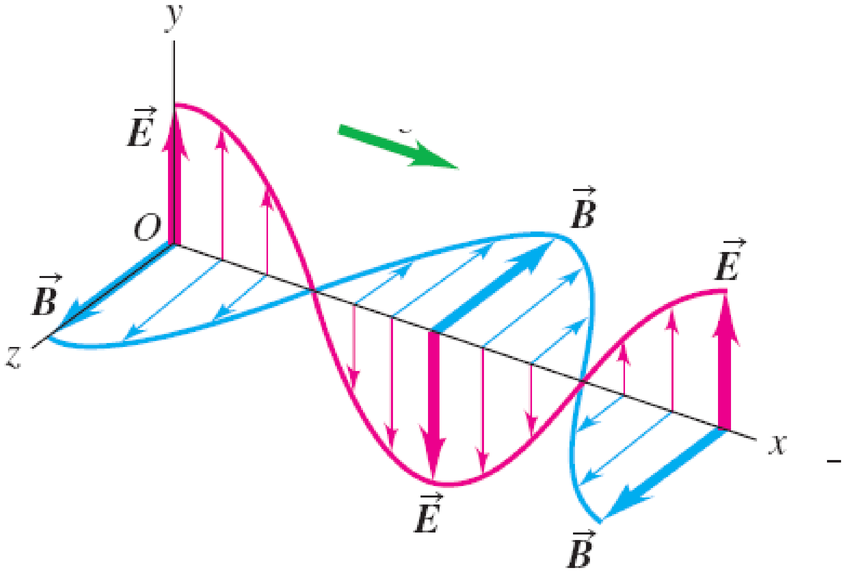
5.) ČESTICE I VALOVI

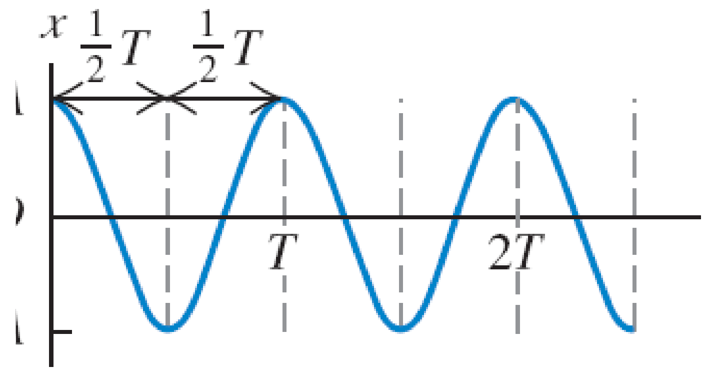




Elektromagnetsko zračenje

$$T = \frac{\lambda}{c} \qquad \nu = \frac{1}{T} \qquad \tilde{\nu} = \frac{1}{\lambda}$$

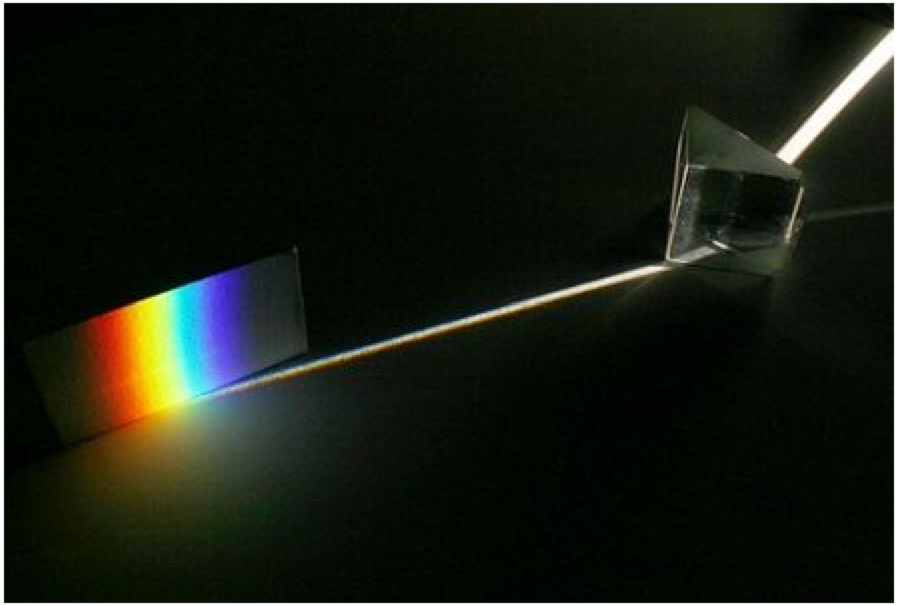


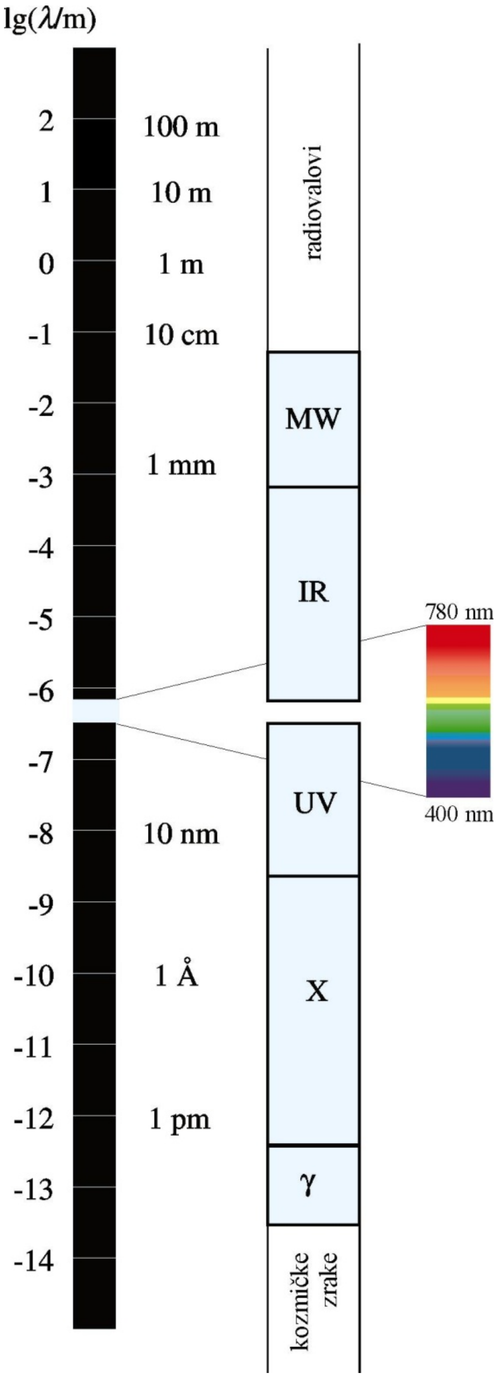


$$I = \frac{P}{A} = \frac{1}{2}\varepsilon_0 c E_{max}{}^2$$

c = 3 x 10^8 m s^{-1} (c = 299 792 458 m s^{-1})

Spektar elektromagnetskog zračenja

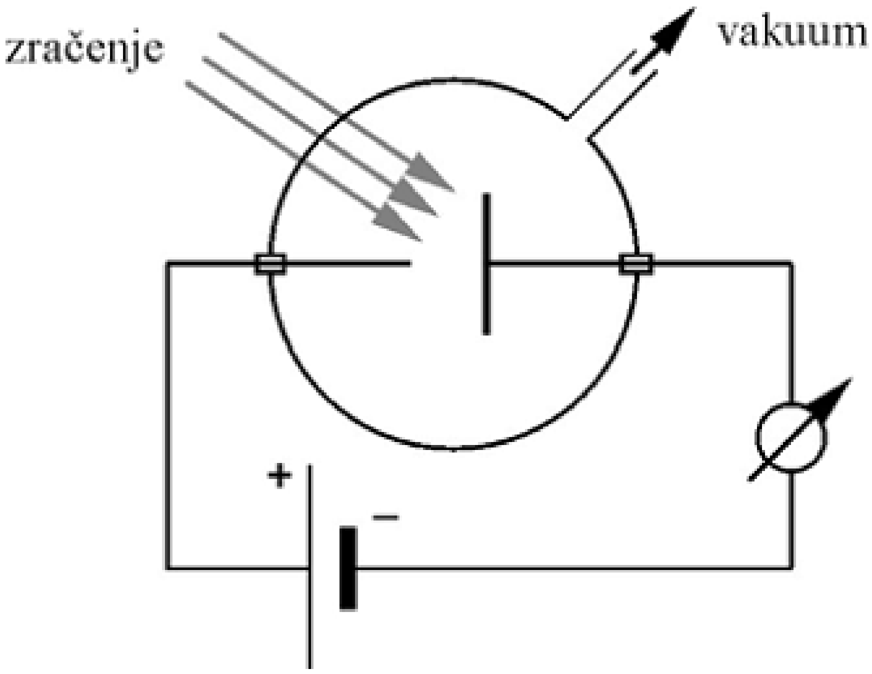




Fotoelektrični efekt

H. Hertz 1887.

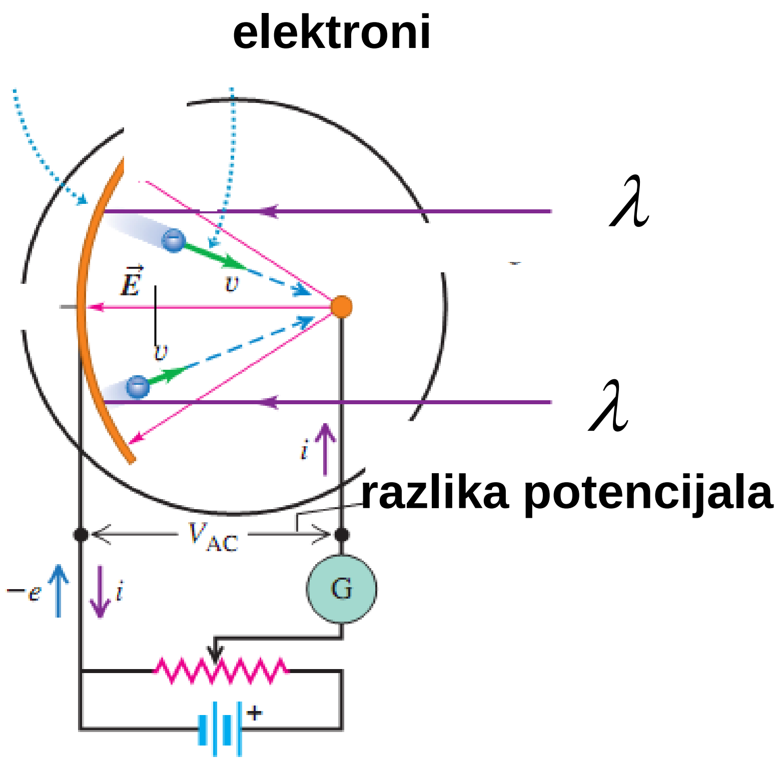
Hallwachs i Lenard

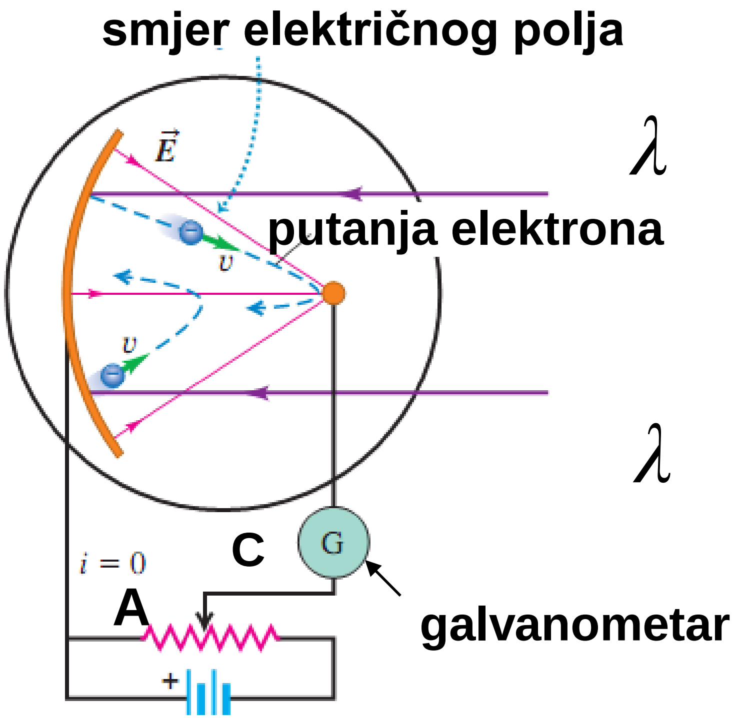


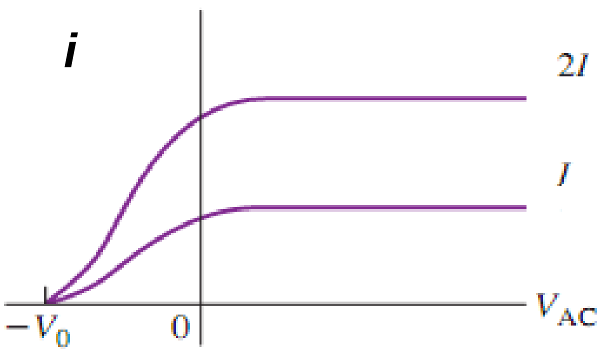
Fotoelektrični efekt

a) $\lambda > \lambda_{max}$ - nema fotoefekta

b) $\lambda < \lambda_{max}$ - fotoefekt







Fotoelektrični efekt

1.Broj elektrona i jakost električne struja proporcionalne su intenzitetu zračenja.

2. Kinetička energija elektrona neovisna je o intenzitetu zračenja. (?)

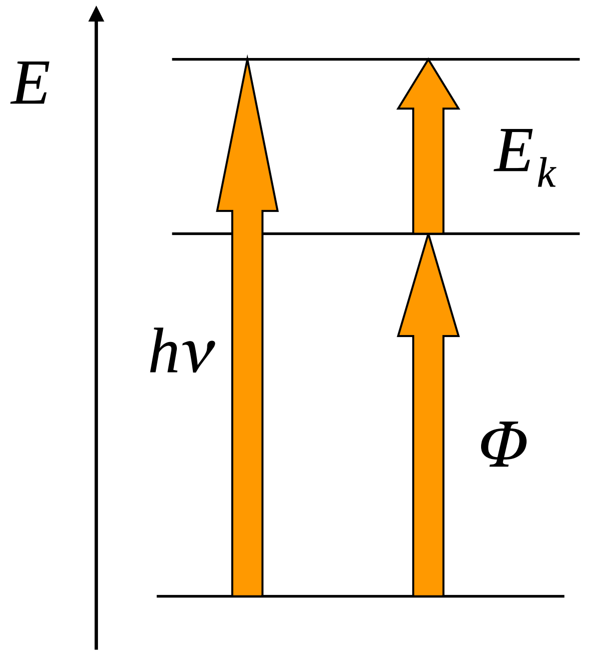
3.Maksimalna kinetička energija elektrona linearna je funkcija frekvencije upadnog zračenja. (?)

4. Zračenje većih valnih duljina od neke granične više ne uzrokuje fotoefekt. (?) (Granična vrijednost ovisi o metalu)

A. Einstein 1905.

$$h\nu = \Phi + E_{\mathrm{k(max)}}$$

$$E_{\mathrm{k(max)}} = h\nu - \Phi$$



Fotoelektrični efekt

1. Broj elektrona i električna struja proporcionalne su intenzitetu zračenja.

$\Rightarrow$ Veći intenzitet – veći broj fotona – veći broj izbačenih elektrona.

2. Kinetička energija elektrona neovisna je o intenzitetu zračenja.

$\Rightarrow$ Kinetička energija elektrona ne ovisi o broju upadnih upadnih fotona (I), već o njihovoj energiji.

3. Maksimalna kinetička energija elektrona raste (linearno) s frekvencijom zračenja.

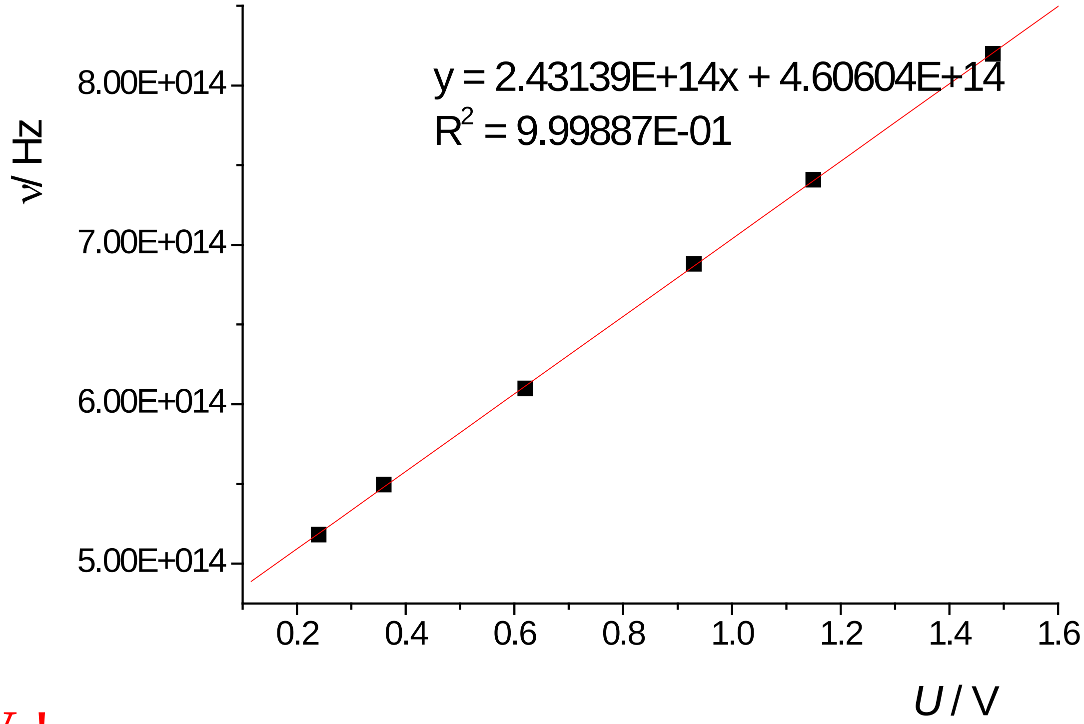
$\Rightarrow$ Kinetička energija elektrona proporcionalna je energiji (frekvenciji) upadnih fotona.

4. Zračenje većih valnih duljina od neke granične više ne uzrokuje fotoefekt.

$\Rightarrow$ Energija fotona manja je od izlaznog rada.

Fotoelektrični efekt

metal	Φ / eV
Al	4,3
Cu	4,7
Au	5,1
Ni	5,1
Si	4,8
Na	2,7

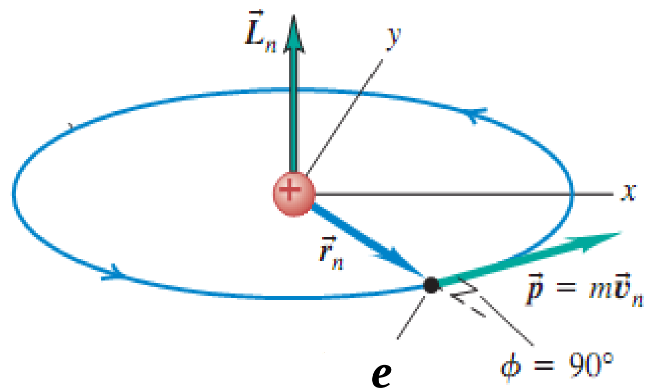


$E_i(\mathrm{Na}) = 5{,}14\ \mathrm{eV}$!

$$\frac{e}{h} = 2{,}43\times10^{14}\,\mathrm{C\ J^{-1}\ s^{-1}} \rightarrow h = \frac{e}{2{,}43\times10^{14}\,\mathrm{C\ J^{-1}\ s^{-1}}} = 6{,}59\times10^{-34}\,\mathrm{J\ s}$$

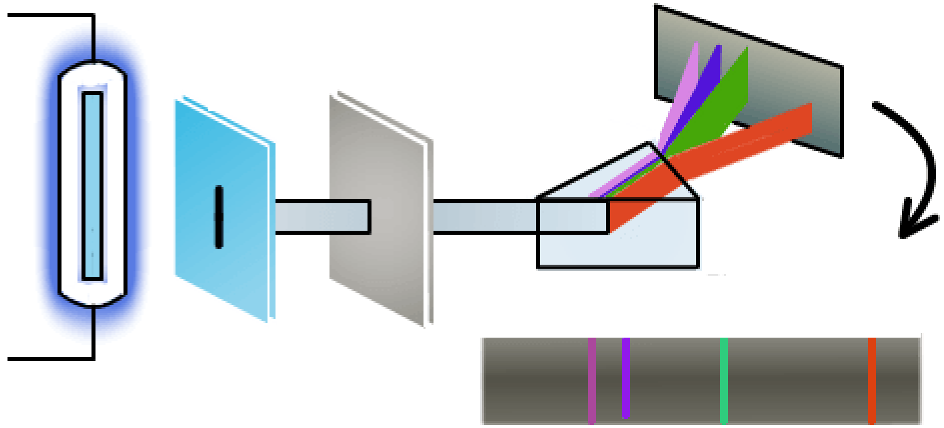
$$\phi = h\nu_{\mathrm{min}} = 6{,}626\times10^{-34}\,\mathrm{J\ s}\ \times\ 4{,}606\times10^{14}\ \mathrm{s^{-1}} = 3{,}05\times10^{-19}\,\mathrm{J} = 1{,}9\ \mathrm{eV}$$

Linijski spektri i Bohrov model atoma

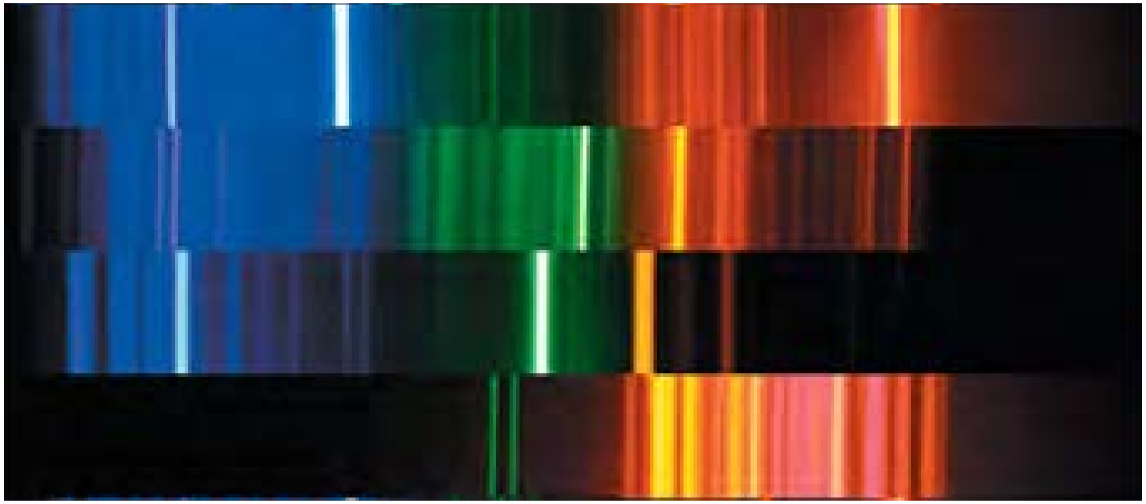


SPEKTROSKOP

Bohrov model atoma



Spektri atoma u vidljivom području elektromagnetskog zračenja



He

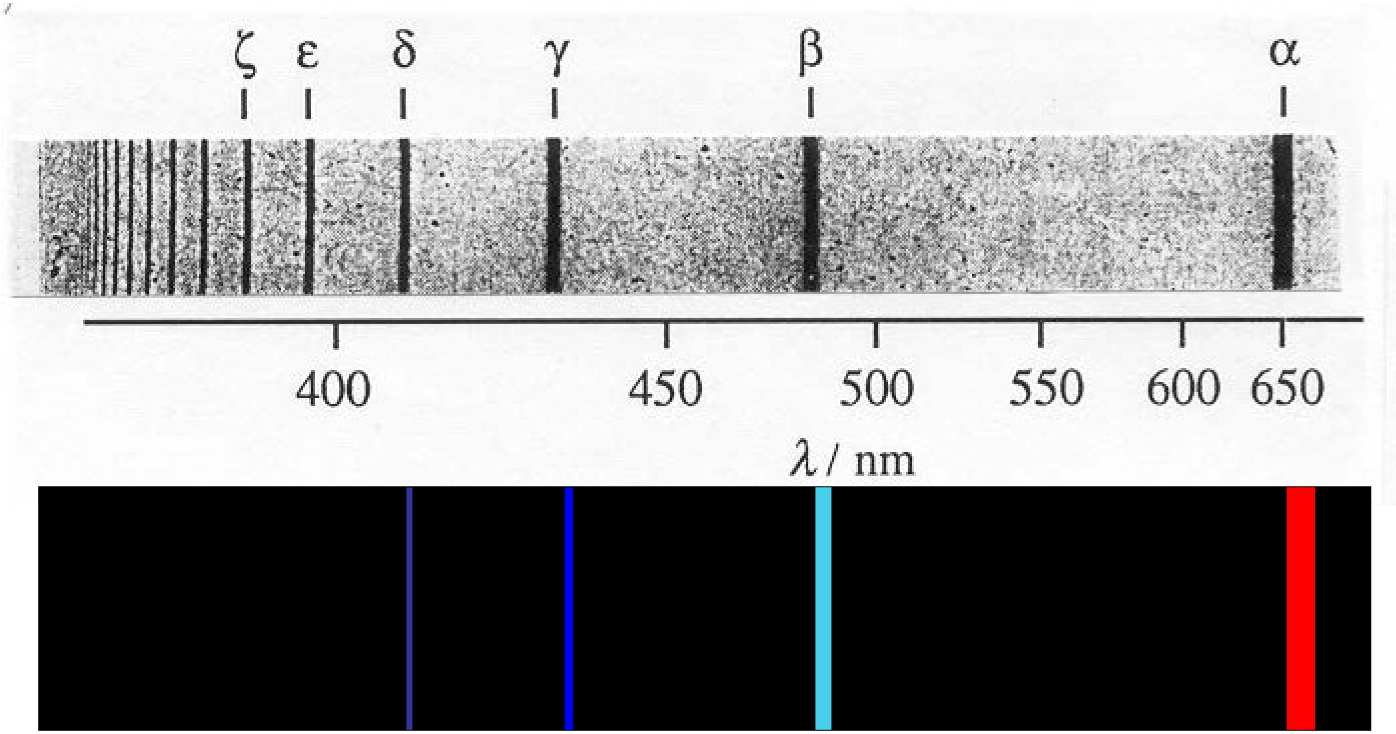
Kr

Hg

Ne

Balmerova serija atoma vodika

Bohrov model atoma



Balmer

$$\lambda / \text{Å} = 3645,6 \frac{n^2}{n^2 - 4} \qquad (n = 3,4,5,6 \ldots)$$

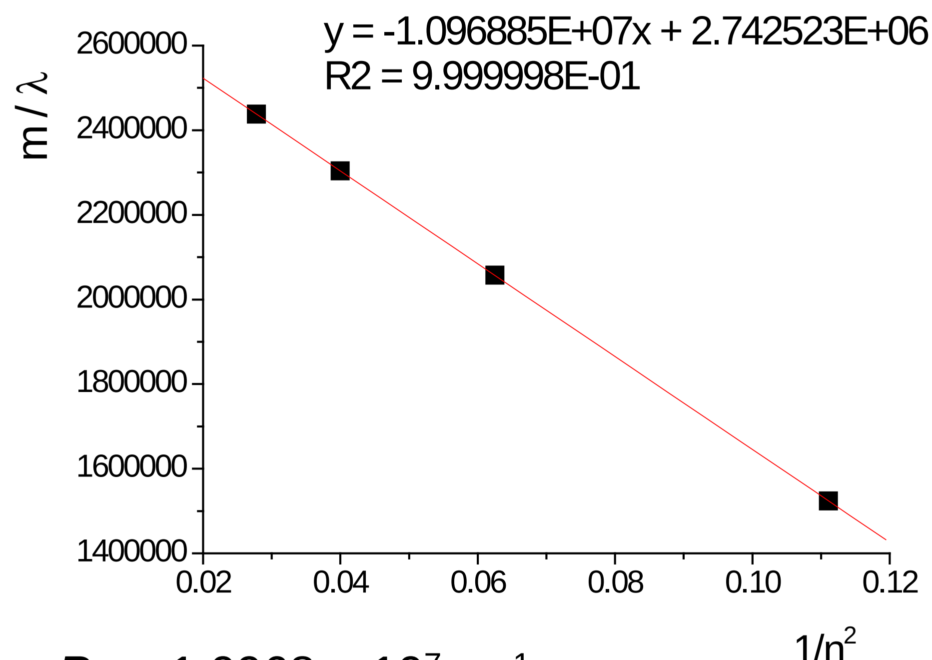
Rydberg

$$\tilde{\nu} = R_{\mathrm{H}} \left(\frac{1}{(2)^2} - \frac{1}{(n')^2} \right) \qquad (n' > 2)$$

SPEKTAR ATOMA VODIKA

Bohrov model atoma

linija	λ /nm
H_α	656,3
H_β	486,1
H_γ	434,1
H_δ	410,2



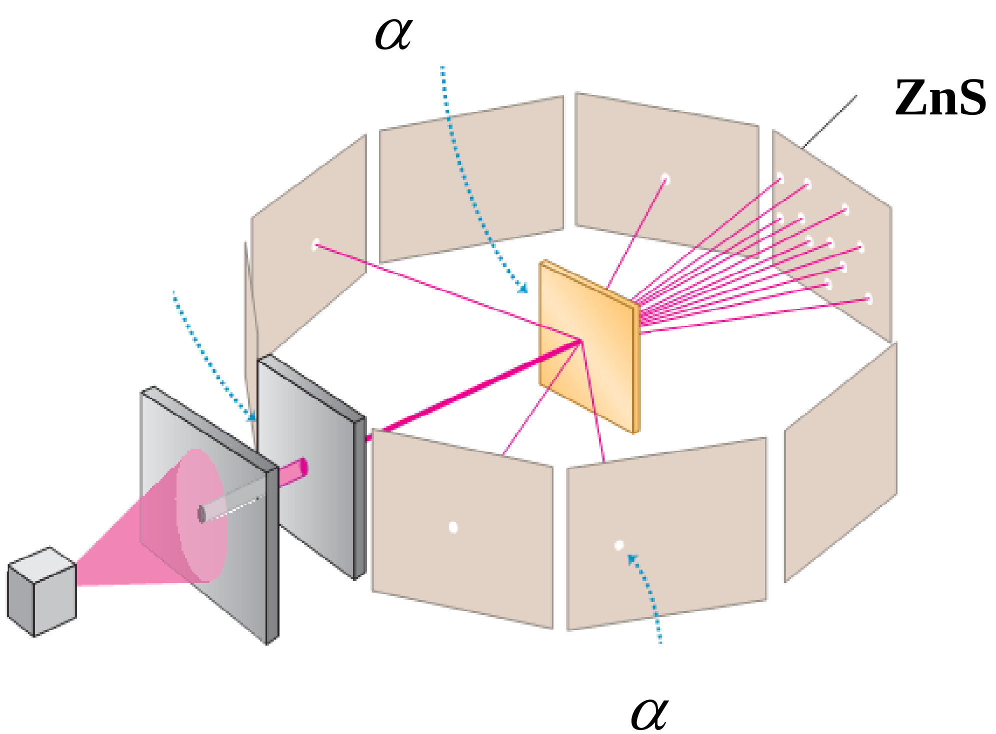
$R_H = 1.0968 \times 10^7\ m^{-1}$

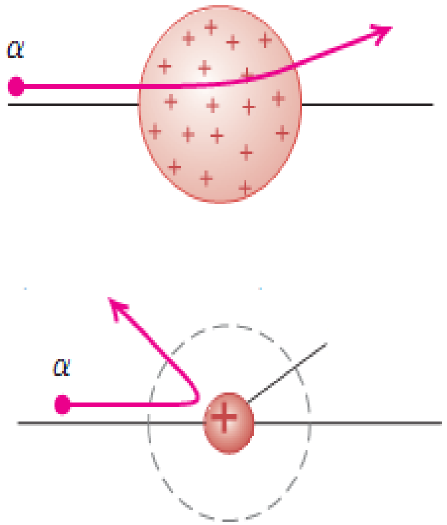
1896. Joseph J. Thompson

otkriće elektrona (atomi se sastoje od manjih čestica)

***plum-pudding* model atoma**

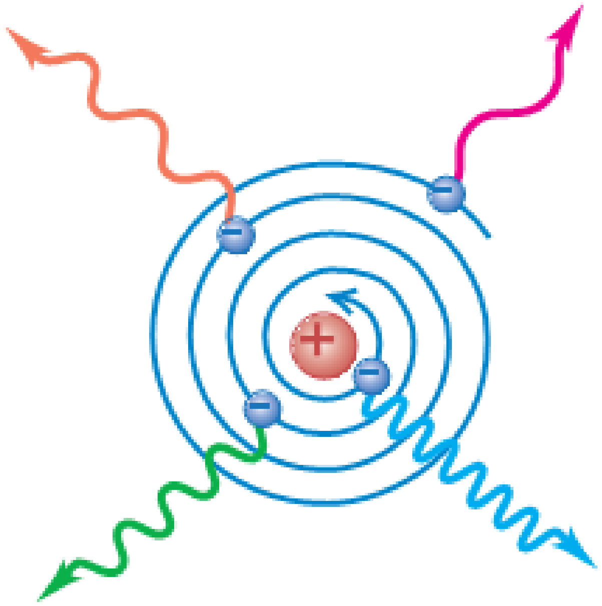
1910. -1911. Ernest Rutherford





Planetarni model atoma - u suprotnosti sa zakonima klasične fizike

Bohrov model atoma



KLASIČNA FIZIKA:

Nejednoliko gibanje nabijenih čestica uzrokuje emisiju elektromagnetskog zračenja

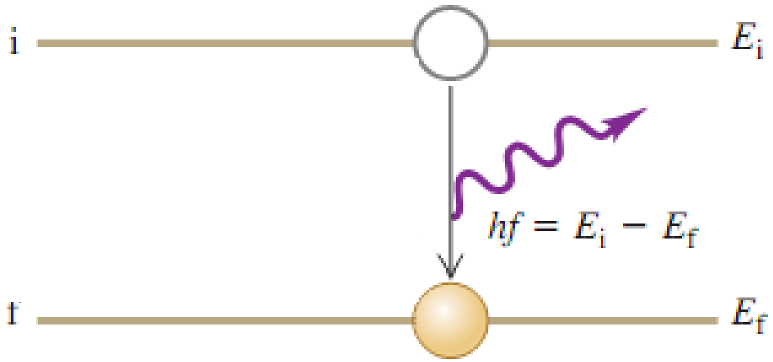
Bohrov model atoma

BOHROVI POSTULATI

1.) Stacionarna stanja

2.) $\Delta E = h\nu$

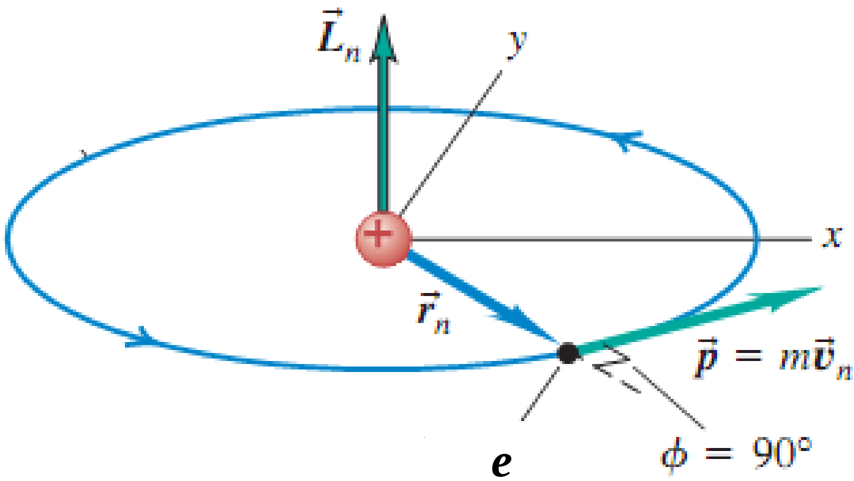
3.) $L = rmv = n\hbar$



$E_i > E_f$

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$H = T + V$$



Bohrov model atoma

$$H = T + V$$

$$T = \frac{mv^2}{2}$$

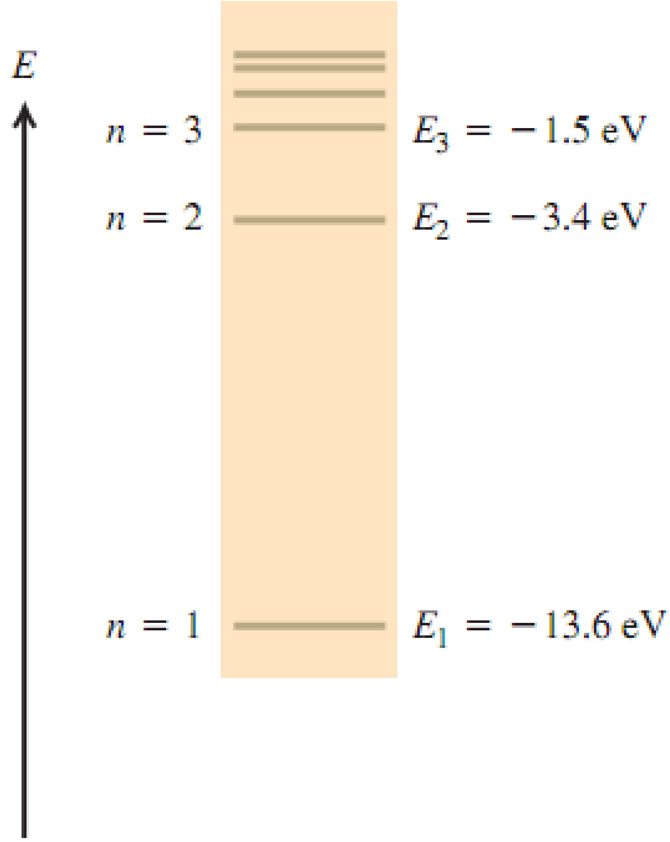
$$V = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

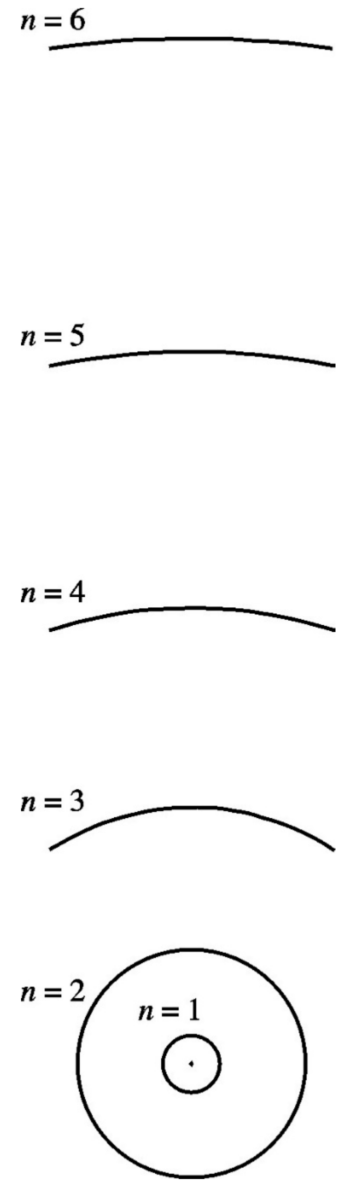
$$v = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar n}$$

$$r = \frac{n\hbar}{mv} = \frac{(4\pi\varepsilon_0)\hbar^2}{m e^2} n^2$$

$$E = -\frac{m e^4}{2(4\pi\varepsilon_0)^2 \hbar^2 n^2} = -\frac{hcR_\infty}{n^2}$$

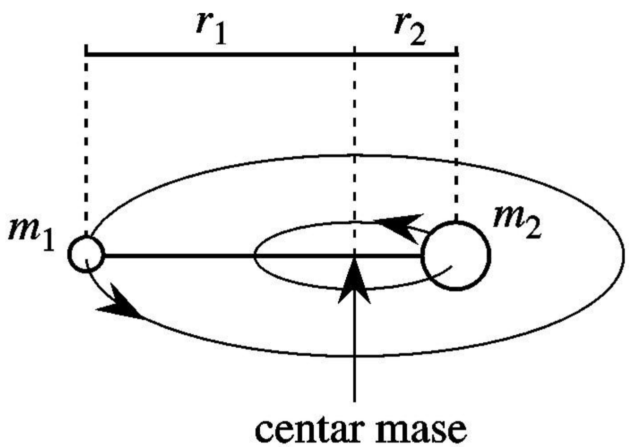
$$\frac{R_H}{R_\infty} = 0,9997$$





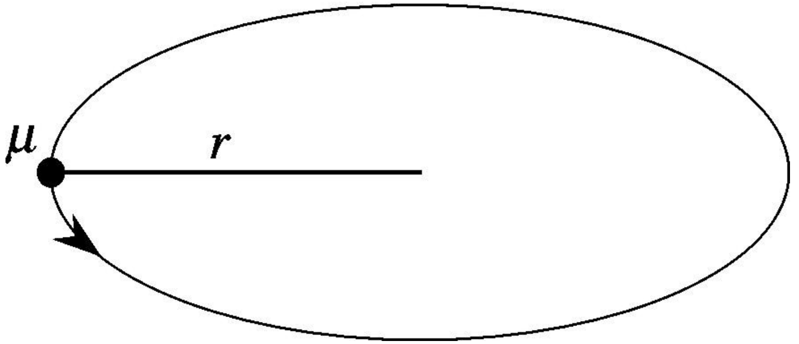
Bohrov model atoma

$$\frac{R_{\mathrm{H}}}{\mu} = \frac{R_{\infty}}{m_{\mathrm{e}}}; \qquad \mu = \frac{m_{\mathrm{e}} m_{\mathrm{p}}}{m_{\mathrm{p}} + m_{\mathrm{e}}}$$



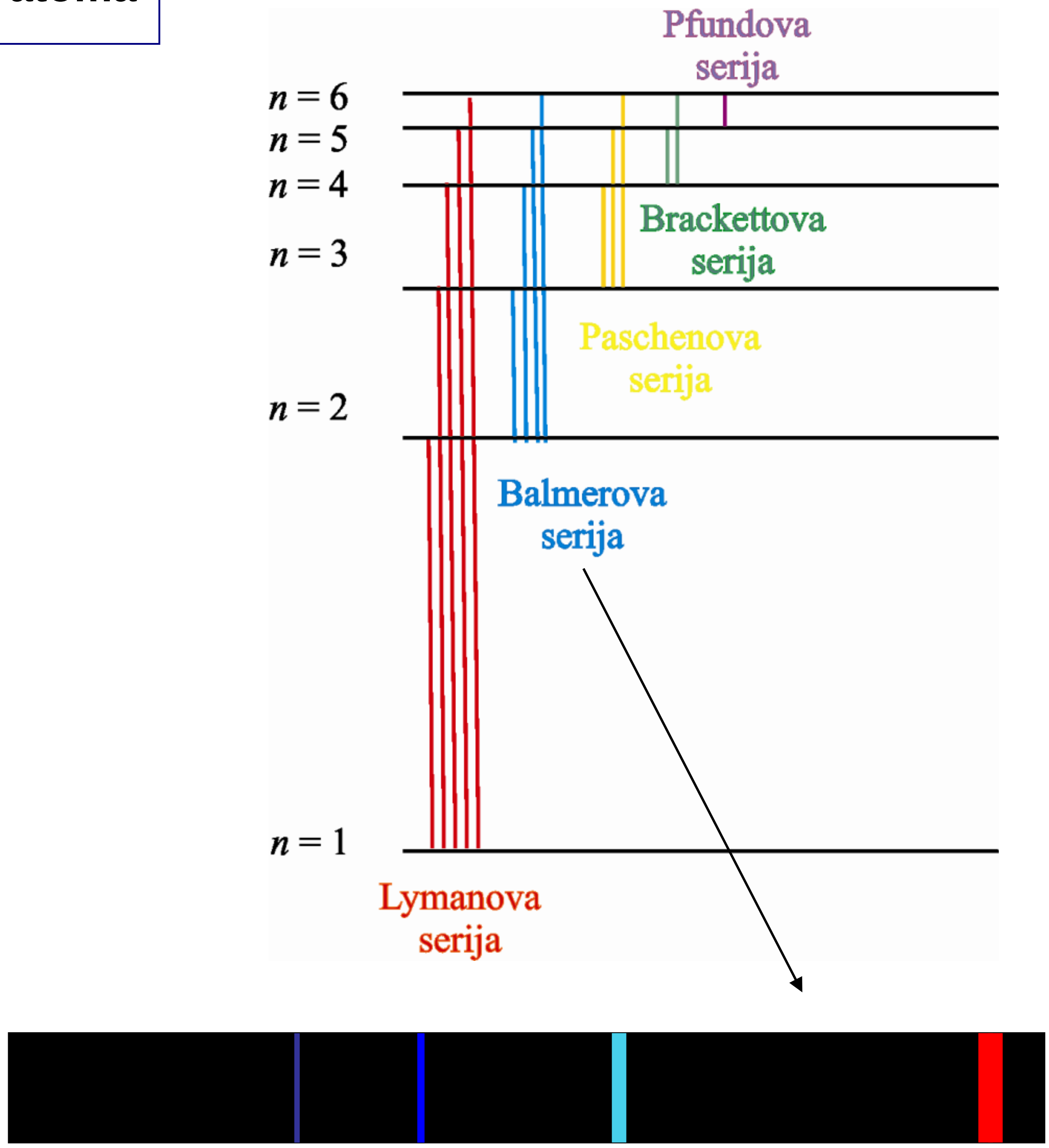
$$r_{\mathrm{CM}} = \frac{\sum_i m_i \vec{r}_i}{\sum_i m_i}$$

$$r_{\mathrm{CM}} = 0 \longrightarrow m_1 r_1 = m_2 r_2$$



$$I = \sum_i m_i r_i^2 \longrightarrow I = \mu r^2$$

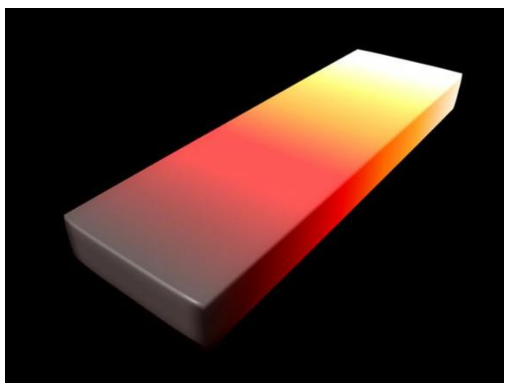
Bohrov model atoma

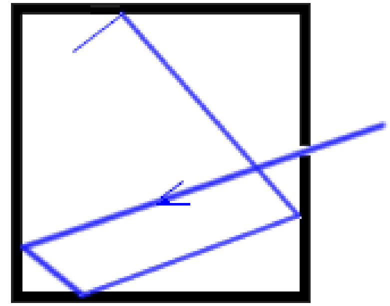


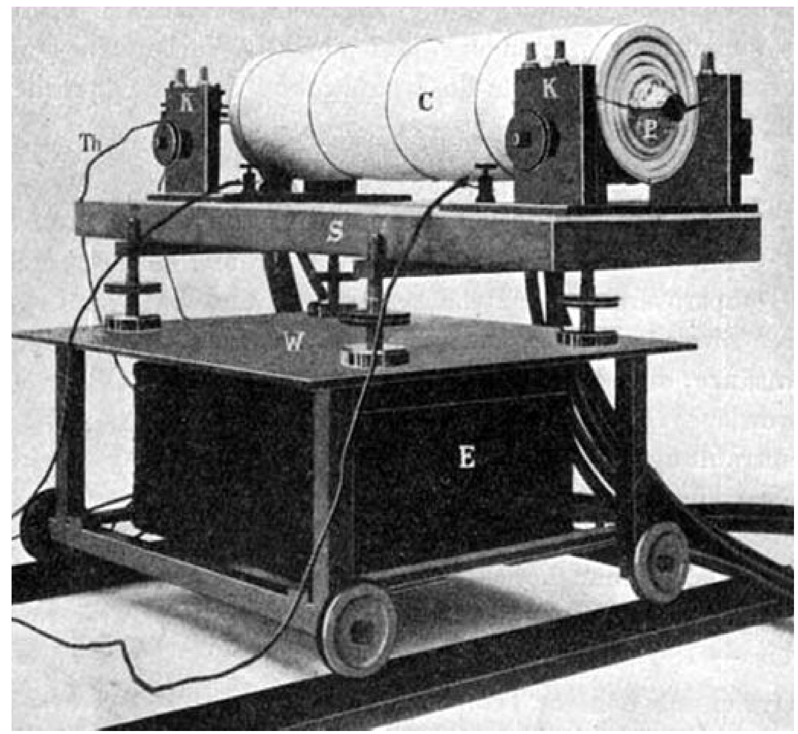
Bohrov model atoma

Serija	n''	Područje zračenja	Jednadžba za $\tilde{\nu}$	n'
Lymanova	1	UV	$R_H\left(\frac{1}{1^2}-\frac{1}{(n')^2}\right)$	2, 3, 4, ...
Balmerova	2	VIS	$R_H\left(\frac{1}{2^2}-\frac{1}{(n')^2}\right)$	3, 4, 5, ...
Paschenova	3	IR	$R_H\left(\frac{1}{3^2}-\frac{1}{(n')^2}\right)$	4, 5, 6, ...
Brackettova	4	IR	$R_H\left(\frac{1}{4^2}-\frac{1}{(n')^2}\right)$	5, 6, 7, ...
Pfundova	5	IR	$R_H\left(\frac{1}{5^2}-\frac{1}{(n')^2}\right)$	6, 7, 8, ...
...	...	...	...	...
	166	radio	$R_H\left(\frac{1}{166^2}-\frac{1}{(n')^2}\right)$	167

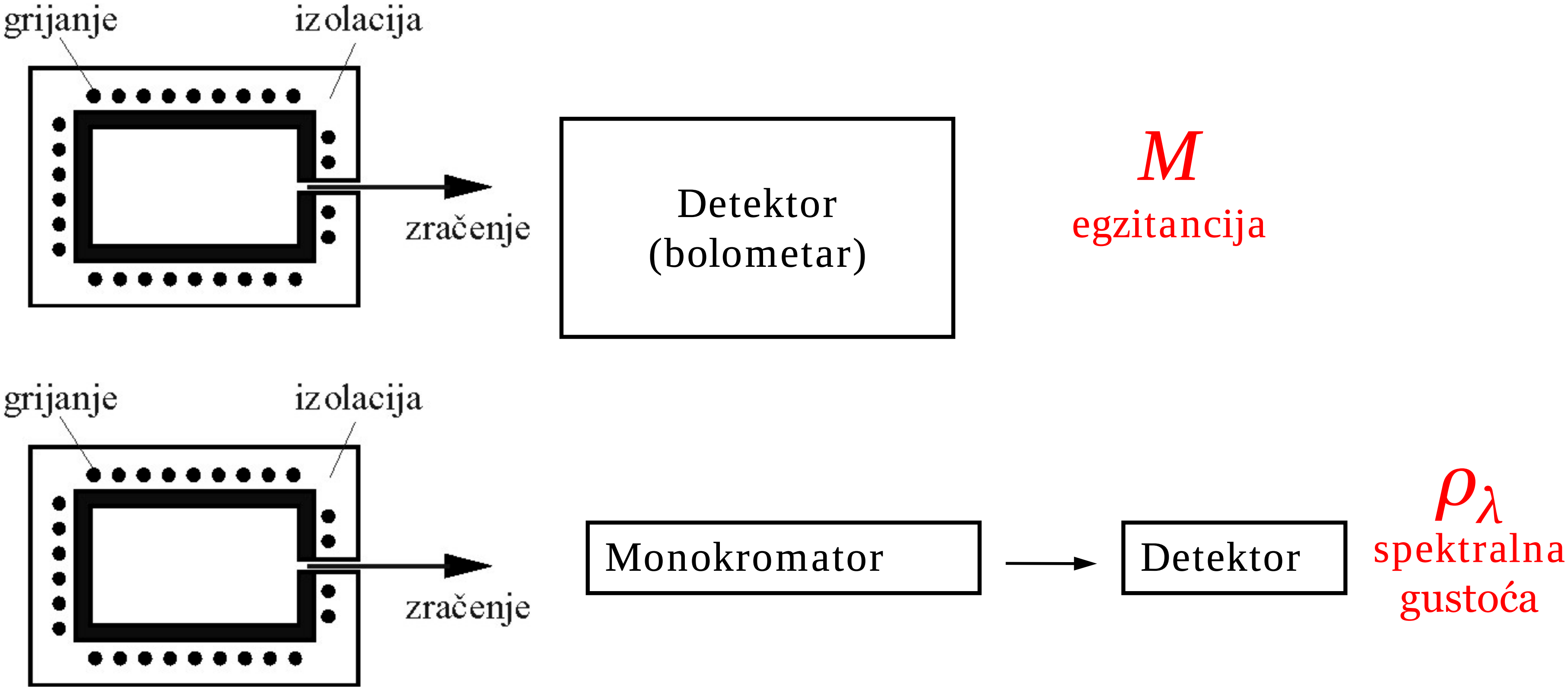
Zračenje crnog tijela







Gustoća energije zračenja ρ_λ



$$P = \frac{dE}{dt}$$

$$\frac{P}{A} = I = M = \sigma T^4$$

Stefan- Boltzmannov zakon

ρ_λ spektralna gustoća zračenja

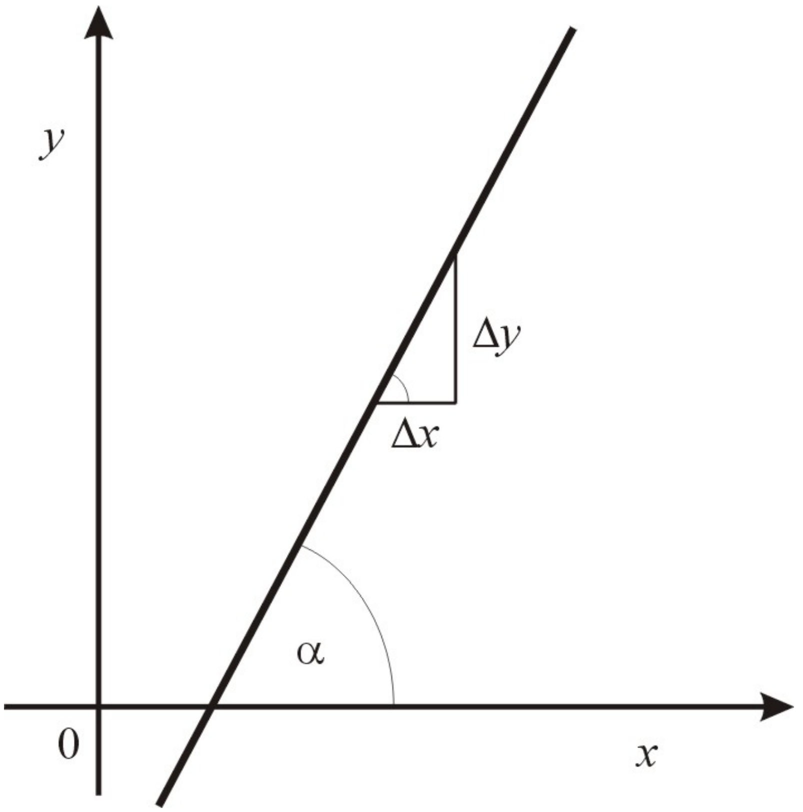
$$\rho_\lambda = \frac{\mathrm{d}\left(E/V\right)}{\mathrm{d}\lambda}$$

$$\rho_\lambda = \lim_{\Delta\lambda \to 0} \frac{E(\lambda + \Delta\lambda) - E(\lambda)}{\Delta\lambda}$$

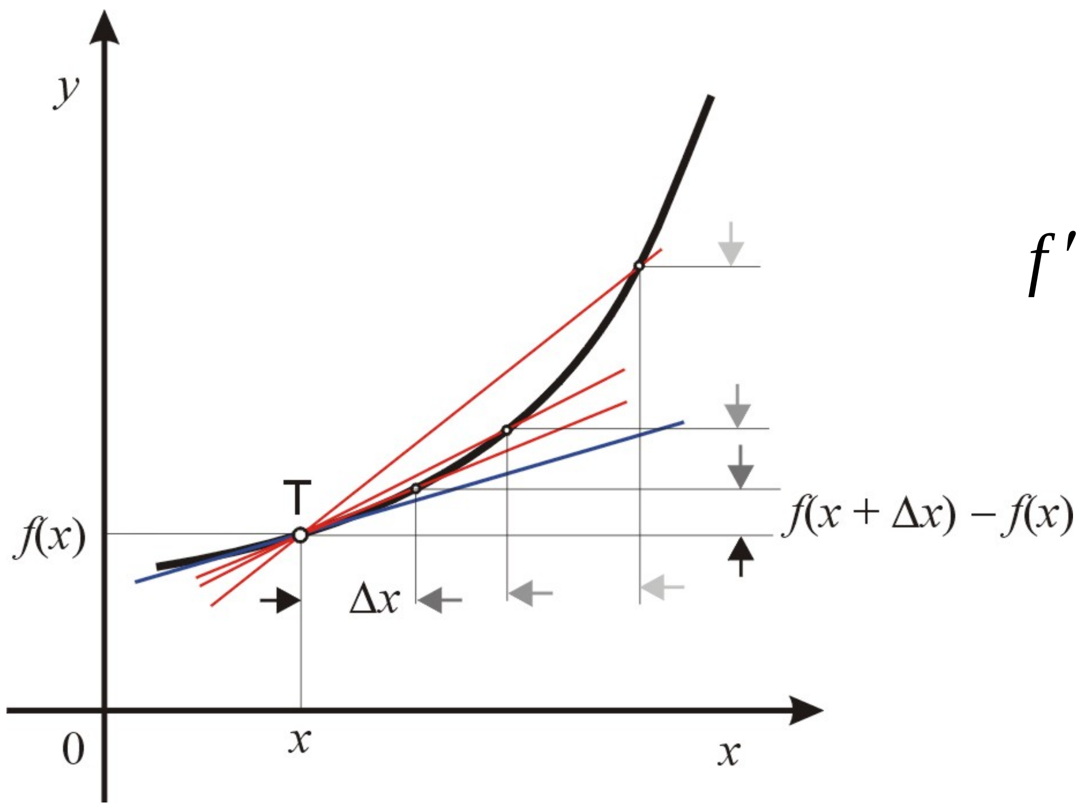
Nagib pravca

$$y = ax + b$$

$$nagib = a = \frac{\Delta y}{\Delta x}$$



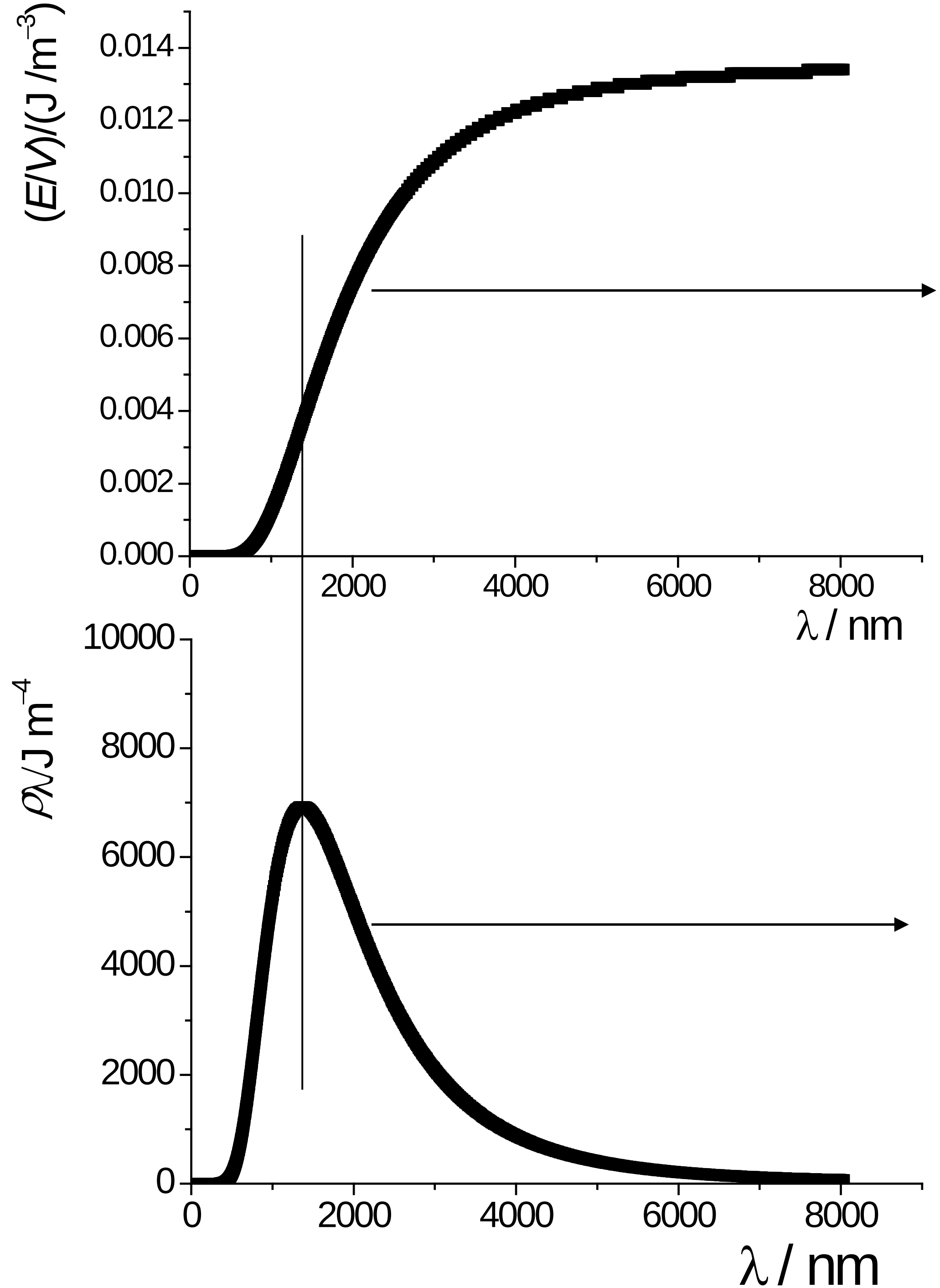
Nagib funkcije u točki T



$$f'(x) = \lim_{\Delta x \to 0} \frac{\Delta f(x)}{\Delta x}$$

Zračenje crnog tijela

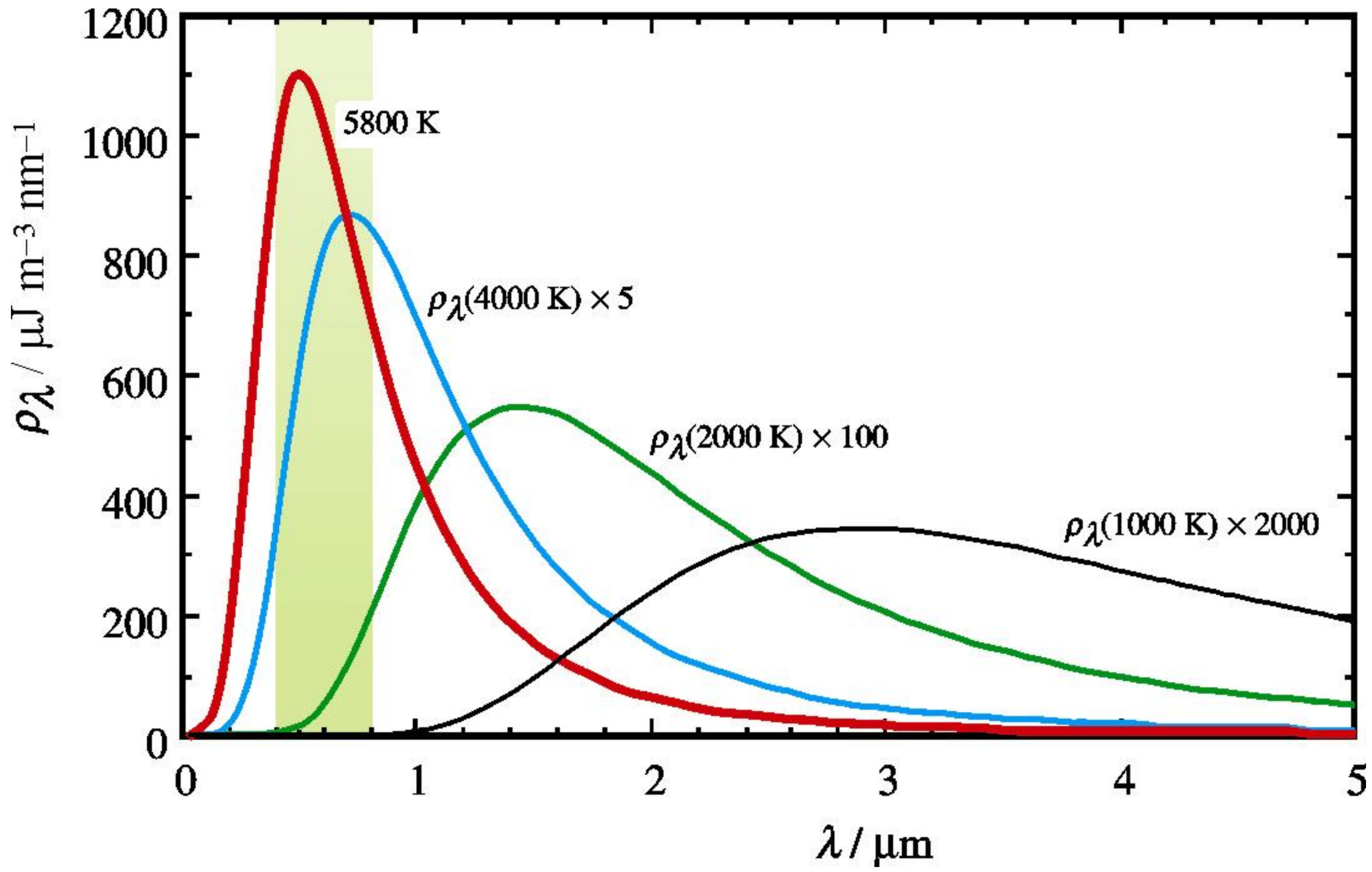
***T* = 2000 K**



$$E/V$$

$$\rho_\lambda = \frac{\mathrm{d}\left(E/V\right)}{\mathrm{d}\lambda}$$

Gustoća energije zračenja ρ_λ



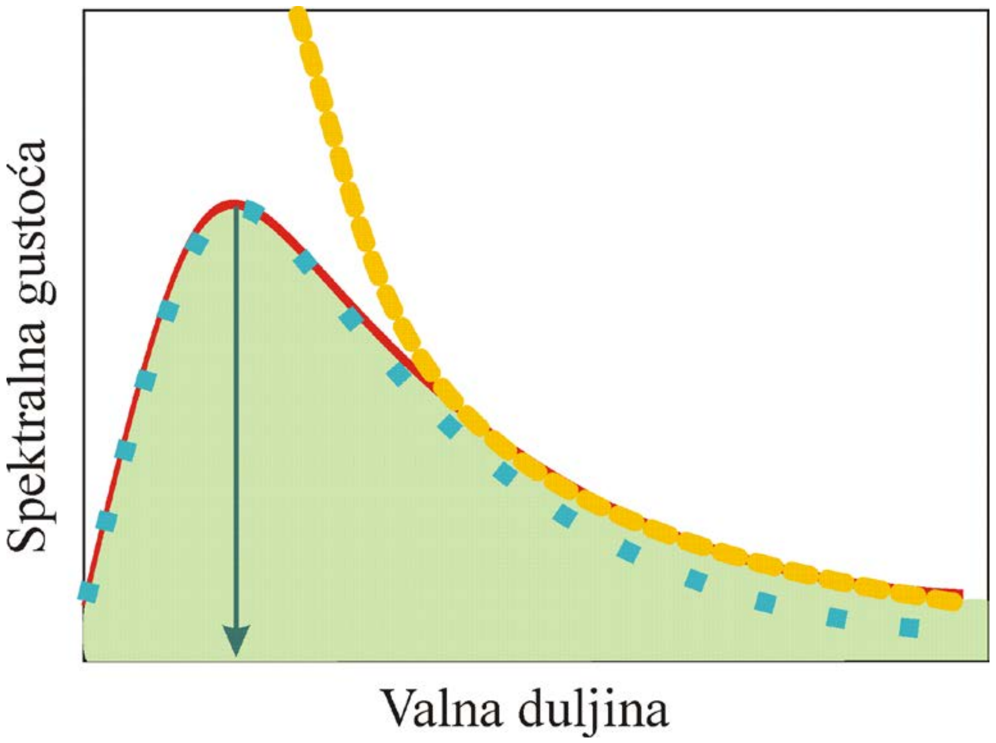
$$T \cdot \lambda_{\max} = \frac{C_2}{5} \qquad C_2 = \frac{hc}{k}$$

Rayleigh i Jeans

Apsorpcija i emisija rezultira stojnim valovima u šupljini

Prosječna energija oscilatora frekvencije v jednaka je $k_B T$

$$\rho_\lambda = \frac{8\pi kT}{\lambda^4}$$



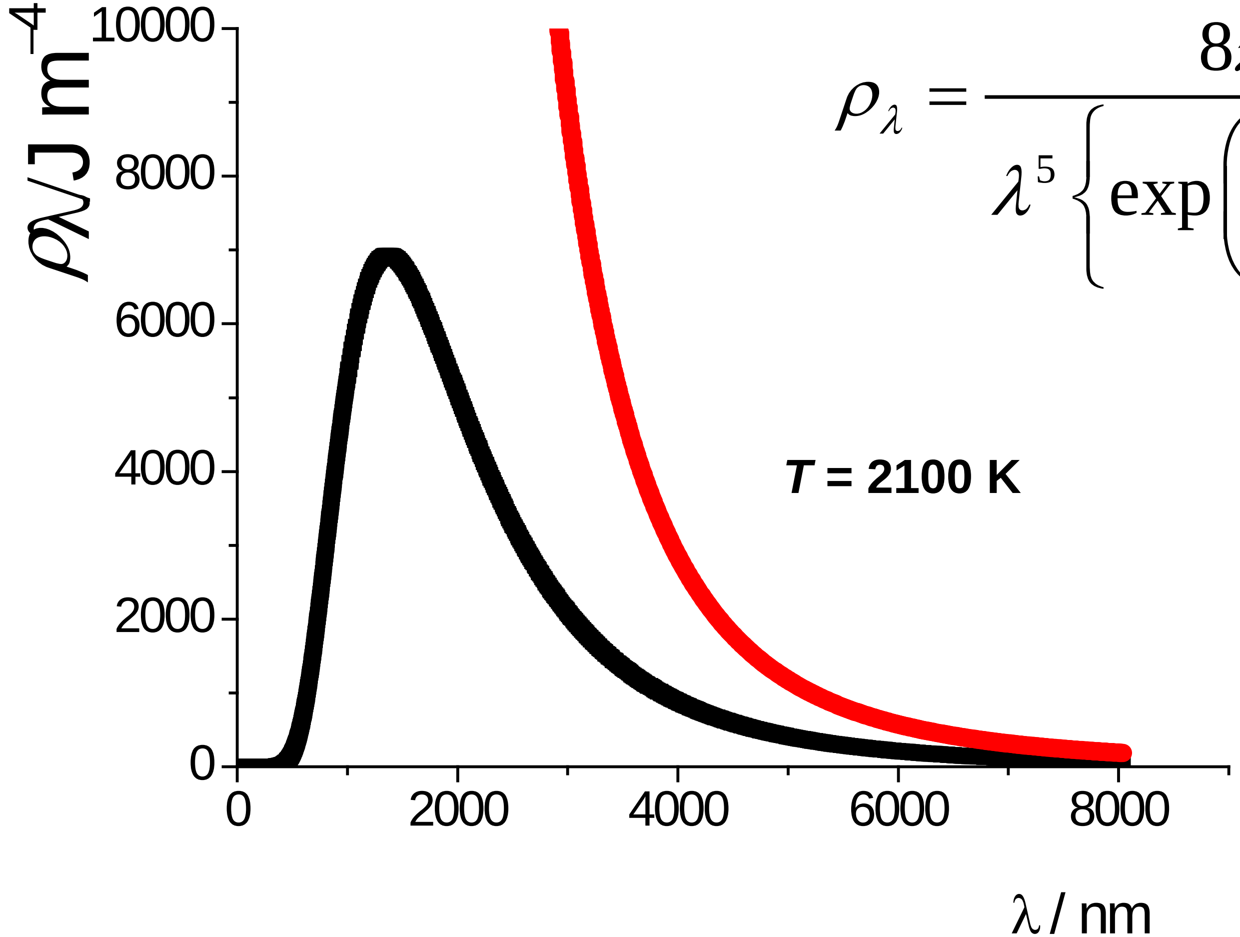
Zračenje crnog tijela

Rayleigh i Jeans

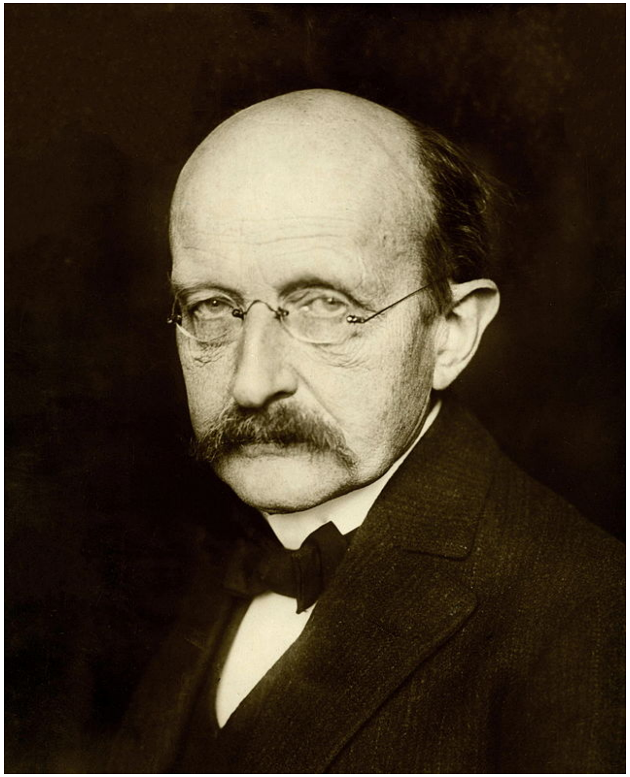
Max Planck

$$\rho_\lambda = \frac{8\pi kT}{\lambda^4} \quad (\blacklozenge)$$

$$\rho_\lambda = \frac{8\pi hc}{\lambda^5\left\{\exp\left(\frac{hc}{\lambda kT}\right)-1\right\}} \quad (\blacklozenge)$$



Max Planck 1900.



$$\rho_\lambda = \frac{8\pi hc}{\lambda^5\left\{\exp\left(\frac{hc}{\lambda kT}\right)-1\right\}}$$

$$\Delta\varepsilon = h\nu = \frac{hc}{\lambda}$$

$$\langle\varepsilon\rangle = \frac{h\nu}{\exp\left(\frac{h\nu}{k_B T}\right)-1}$$

Oscilatori (atomi) primaju energiju samo u određenim višekratnicima frekvencije (kvantima)

Kad su kvanti veliki (visoka frekvencija, mala valna duljina) oscilatori se ne mogu pobuditi pri nižim temperaturama.

Valna priroda čestica

Louis-Victor de Broglie 1924.

$$E_f = pc = h\nu = h\frac{c}{\lambda}$$

foton

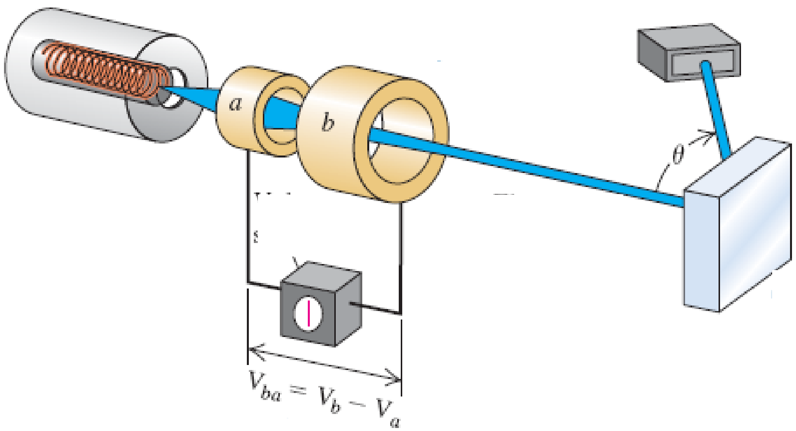
$$\lambda = \frac{h}{p}$$

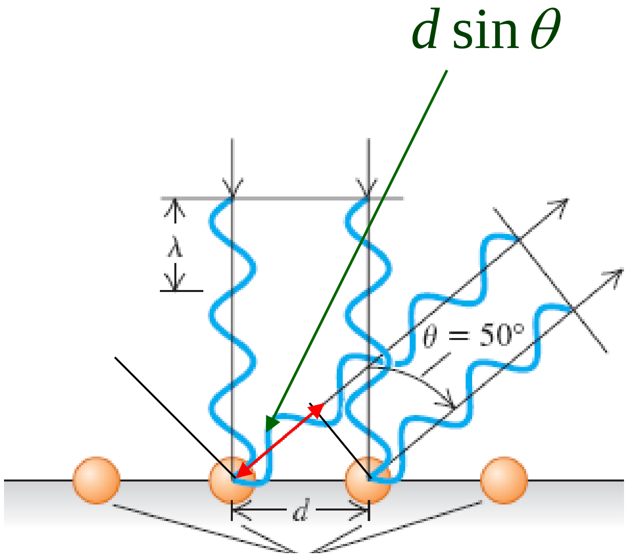
čestica

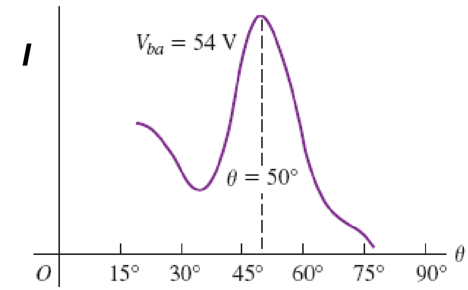
$$\lambda = \frac{h}{mv}$$

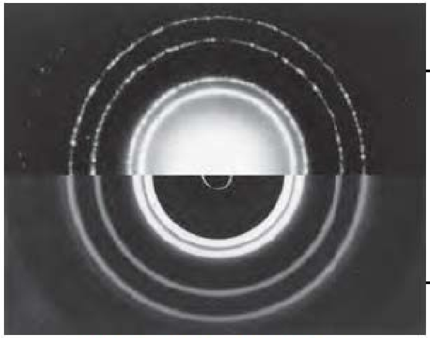
C. J. Davisson & L. Germer

- difrakcija (karakteristika valova) elektrona (čestica)









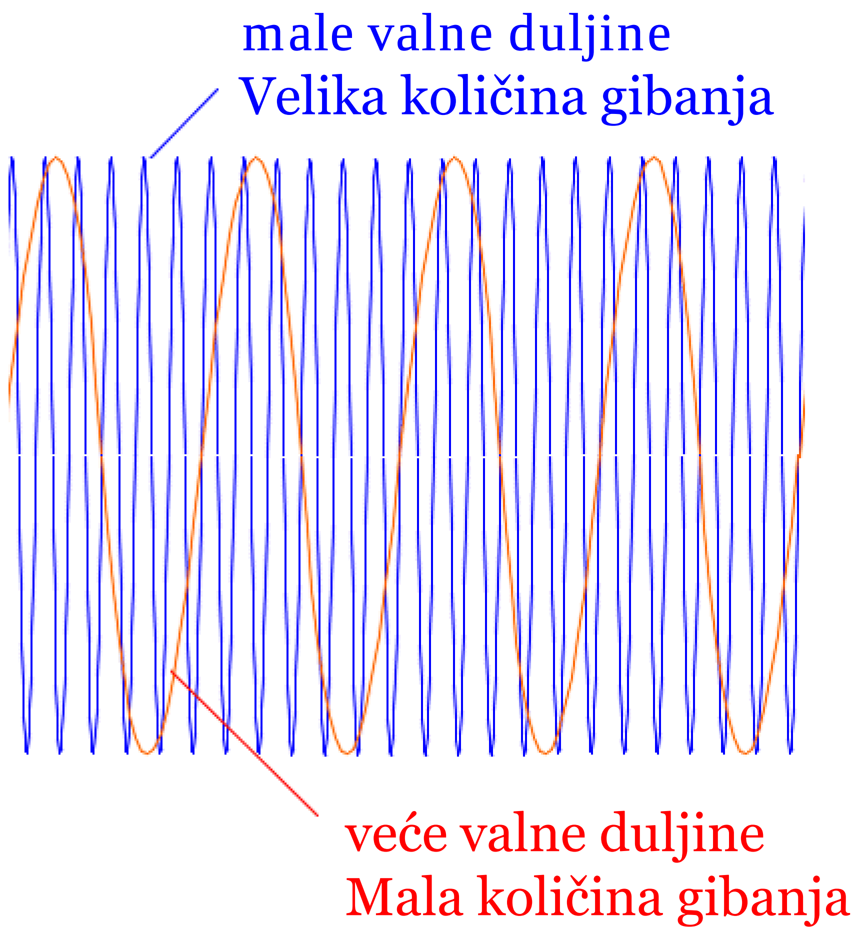
Difrakcija roentgenskih zraka (λ = 71 pm, Al)

Difrakcija elektrona (E_k = 600 eV, Al)

$$\lambda = \frac{h}{p} \qquad eV_{ba} = \frac{p^2}{2m}$$

$$d \sin\theta = m\lambda \qquad m = 1, 2, 3\ldots$$

$$\lambda = \frac{h}{p}$$



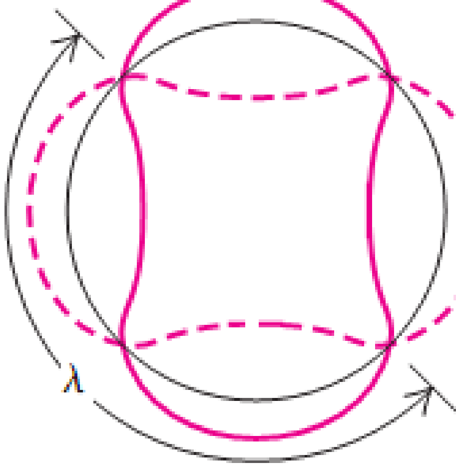
Valna priroda čestica

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

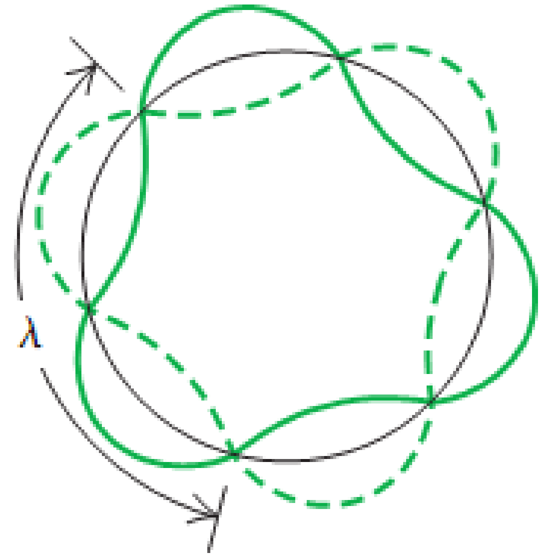
$$p = \frac{h}{\lambda}$$

PRIMJERI	m / kg	v / m s^{-1}	p / kg m s^{-1}	Λ
Zelena svjetlost	0	$3 \cdot 10^{8}$	$1{,}2 \cdot 10^{-27}$ ←	550 nm
Elektron	$9{,}1 \cdot 10^{-31}$	$3 \cdot 10^{8}$	$2{,}72 \cdot 10^{-22}$ →	2,41 pm
NaCl 1 mg (v = 1 mm h^{-1})	$1 \cdot 10^{-6}$	10^{-7}	$2{,}7 \cdot 10^{-13}$ →	$2{,}4 \cdot 10^{-21}$ m

Valna priroda čestica i Bohrov model atoma



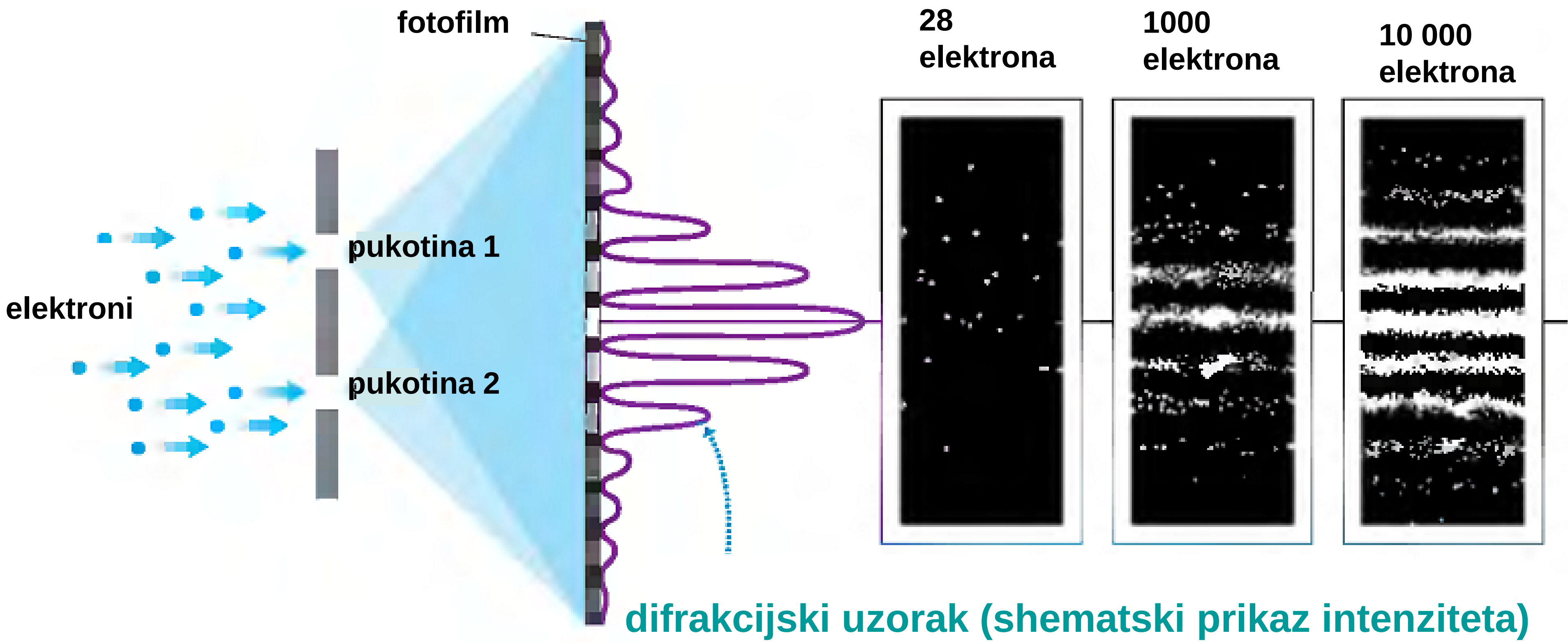
$n = 2$



$n = 3$

$$\left.\begin{aligned} n\lambda &= 2\pi r \\ \lambda &= \frac{h}{p} \end{aligned}\right\} \quad rmv = n\frac{h}{2\pi}$$

Valna priroda čestica



Klasična fizika

Čestica se kreće u skladu sa zakonima klasične mahanike (poznate koordinate i brzina čestice)

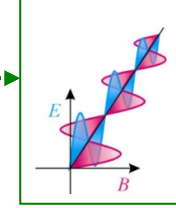
Energija sustava (čestice) može poprimiti bilo koji iznos (kontinuiranost energije)

-čestice i valovi su dva odvojena koncepta

Električni naboj koji se giba nejednoliko izvor je elektromagnetskog zračenja

EMZ

$E = h\nu$

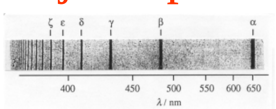


KVANTNA TEORIJA

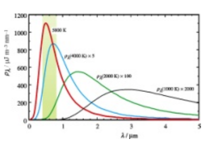
Valna priroda čestica

Eksperimenti

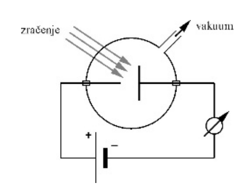
Linijski spektri



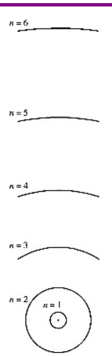
Zračenje crnog tijela



Fotoelektrički efekt



Model atoma



Pitanja za ponavljanje

1. Kako su rezultati mjerenja EMZ crnog tijela doprinijeli razvoju kvantne kemije?
2. O čemu ovisi energija gustoće zračenja u crnom tijelu?
5. Kako je Max Planck objasnio spektar zračenja crnog tijela?

6. Što je fotoelektrični efekt?
7. Kako su rezultati mjerenja fotoelektričnog efekta doprinijeli razvoju kvantne kemije?
8. Einsteinovo objašnjenje fotoelektričnog efekta.

9. Što je elektromagnetsko zračenje?
10. Kako se dobivaju emisijski spektri tvari?
11. Koja je razlika između kontinuiranih i linijskih spektara?
12. Kako pojava linija u spektrima ukazuje na kvantiziranost energije?
13. Izvedite izraz za energije atoma po Bohrovom modelu.
14. Opišite Thompsonov, Rutherfordov i Bohrov model atoma.
15. Kako energija atoma vodika ovisi o glavnom kvantnom broju?
16. Kako veličina atoma vodika prema Borovu modelu ovisi o glavnom kvantnom broju?

17. Objasnite de Brogliejevu hipotezu.
18. Koji pokusi ukazuju na valnu prirodu čestica?