(*)

$P = 200\ W$

$\nu = 94.3\ MHz$

$d = 15\ km$

$V = 8\ l = 8\ dm^3$

$N_{fotona} = ?$

$$P_T = \frac{P}{4\pi d^2} = \frac{200\ W}{4\pi (15 \cdot 10^3)^2 m^2}$$

$$= 0.07 \cdot 10^{-6}\ W/m^2 = \underline{\underline{7 \cdot 10^{-8}\ W/m^2}}$$

$$P_T = \frac{c}{4} U_T \Rightarrow U_T = \frac{4 P_T}{c}$$

$$= \frac{4 \cdot 0.07 \cdot 10^{-6}\ W/m^2}{3 \cdot 10^8\ m/s}$$

$$= 0.0933\dot{} \cdot 10^{-14}\ J/m^3$$

energija u volumenu $E_T = U_T \cdot V = 0,0933\dot{} \cdot 10^{-14}\ J/m^3 \cdot 8 \cdot 10^{-3}\ m^3$

$$= 0,7467\dot{} \cdot 10^{-17}\ J$$

$E_T = N_{fotona} \cdot h\nu$

$$\Rightarrow N_{fotona} = \frac{E_T}{h\nu} = \frac{0,7467\dot{} \cdot 10^{-17}\ J}{6.626 \cdot 10^{-34}\ J\,s \cdot 94.3 \cdot 10^6\ s^{-1}}$$

$$= 0.00119499 \cdot 10^{-17+34-6}$$

$$= \underline{\underline{119499 \cdot 10^3}} = 119\,499\,000$$

$$= 1.19499 \cdot 10^8$$

(*)

$\lambda_{prag} = 6000 \text{ Å}$

$\lambda = 4000 \text{ Å}$

$E_{k_{max}} = ?$

$$h\nu = E_k + \phi$$

$$h\nu = E_k + h\nu_{prag}$$

$$\nu = \frac{c}{\lambda}$$

$$\frac{hc}{\lambda} = E_k + \frac{hc}{\lambda_{prag}}$$

$$E_k = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_{prag}}\right) =$$

$$= 12.40 \cdot 10^{-7} \text{ eV}\,\text{m} \left(\frac{1}{4 \cdot 10^{-7}\,\text{m}} - \frac{1}{6 \cdot 10^{-7}\,\text{m}}\right)$$

$$= 12.40 \text{ eV} \; \frac{3-2}{12}$$

$$= \frac{12.40}{12} \text{ eV} = 1.0333 \text{ eV}$$

$$= 1,65 \cdot 10^{-19} \text{ J}$$

(*)

$\lambda = 10^{-13}\,m$

$\theta = 75°$

a) $\lambda' = ?$

$E_\gamma - E_\gamma' = ?$

b) $E_e' = ?$

Zoe: $p_\gamma + 0 = p_\gamma' + p_e'$

Zoe: $E_\gamma + E_e = E_\gamma' + E_e'$

a) $\lambda' = \lambda + \lambda_c (1 - \cos\theta)$ $\quad 0.74$

$\lambda' = 0.1 \cdot 10^{-12}\,m + 2.43 \cdot 10^{-12}\,m\,(1 - \cos 75°)$

$\lambda' = (0.1 + 1.80) \cdot 10^{-12}\,m$

$\lambda' = 1.9 \cdot 10^{-12}\,m$

$E_\gamma - E_\gamma' = \underbrace{E_e' - E_e}_{\Delta E_e} \Rightarrow \Delta E_e = h\nu - h\nu'$

$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right)$

$= 1.24 \cdot 10^{-6}\,eV\,m \left(\frac{1}{0.1 \cdot 10^{-12}\,m} - \frac{1}{1.9 \cdot 10^{-12}\,m}\right)$

$= 1{,}24 \cdot 10^{6}\,eV \underbrace{\left(\frac{1}{0.1} - \frac{1}{1.9}\right)}_{9.47}$

$= 11{,}74 \cdot 10^{6}\,eV = 11.74\,MeV$

$\{ = 1.88 \cdot 10^{-12}\,J$

b) $E_e' = m_e c^2 + E_{k,e}' = m_e c^2 + \Delta E_e$ $\quad \begin{cases} E_e = m_e c^2 \\ E_e' = m_e c^2 + E_{k,e}' \end{cases}$

$= 0{,}5\,MeV + 11.74\,MeV$

$= 12.24\,MeV$

$\{ = 1.96 \cdot 10^{-12}\,J$

$$E_e'^2 = m_e^2 c^4 + p_e'^2 c^2$$

$$\Rightarrow \quad pc = \sqrt{E_e'^2 - (m_e c^2)^2}$$

$$pc = \sqrt{12.24^2 - 0.5^2}\ \text{MeV}$$

$$pc = 12.23\ \text{MeV} \Rightarrow p = 12.23\ \text{MeV}/c$$

$$\} = 6{,}52 \cdot 10^{-21}\ \text{kg m/s}$$

$m_e c^2 = 0{,}5\ \text{MeV}$

$E_k' = 11.74\ \text{MeV}$

$\Rightarrow$ nije opravdana nerelativistička aproksimacija koja vrijedi za $E_k \ll m_e c^2$

(*)

$\Gamma = \Delta E = 1{,}1\,eV$ $\qquad$ $E = 1{,}6\,keV$

a) $\tau = \Delta t = ?$ $\qquad$ b) $\Delta\lambda = ?$

a)

$$\Delta E \cdot \Delta t \geq \frac{\hbar}{2}$$

$$\Delta t \geq \frac{\hbar}{2\Delta E} = \frac{h \cdot c}{2 \cdot 2\pi \, \Delta E \cdot c} = \frac{12{,}40 \cdot 10^{-7}\, eV\,m}{4\pi \cdot 1{,}1\,eV \; 3 \cdot 10^8\, m/s}$$

$$= 0{,}3 \cdot 10^{-7} \cdot 10^{-8}\, s = \underline{3 \cdot 10^{-16}\, s} = \tau$$

srednji življenjski čas

b)

$$E = 1{,}6\,keV = h\nu = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$$

$$= \frac{12{,}40 \cdot 10^{-7}\, eV\,m}{1{,}6 \cdot 10^3\, eV}$$

$$= 7{,}75 \cdot 10^{-10}\, m$$

$$\lambda = \frac{hc}{E}$$

$$d\lambda = -\frac{hc}{E^2}\, dE$$

$$\Rightarrow \Delta\lambda = \frac{hc}{E^2}\Delta E \quad \text{ali} \quad \Delta E = \frac{E^2}{hc}\Delta\lambda = \left(\frac{E}{hc}\right)^2 hc\,\Delta\lambda = hc\,\frac{\Delta\lambda}{\lambda^2}$$

$$\Rightarrow \Delta\lambda = 12{,}40 \cdot 10^{-7}\, eV\,m \; \frac{1{,}1\,eV}{(1{,}6 \cdot 10^3)^2\, eV^2} = \underline{0{,}53 \cdot 10^{-12}\, m}$$

$$\Delta E \cdot \Delta t \geq \frac{\hbar}{2}$$

$$hc\,\frac{\Delta\lambda}{\lambda^2}\,\Delta t \geq \frac{\hbar}{2}$$

$$\Delta\lambda \geq \frac{h \cdot c}{2 \cdot 2\pi}\,\frac{1}{\Delta t}\,\frac{\lambda^2}{hc}\,\frac{1}{c} = \frac{(7{,}75 \cdot 10^{-10})^2\, m^2}{2 \cdot 2\pi\,(3 \cdot 10^{-16}\, s)(3 \cdot 10^8\, m/s)} =$$

$$\Delta\lambda_{min} = \underline{0{,}531 \cdot 10^{-12}\, m}$$

(X)

$^{1}_{1}H$, $^{2}_{1}H$ (deuterij)

$n = 3 \rightarrow m = 2$

λ_{H1} , $\lambda_{deut} \equiv \lambda_{H2} = ?$

$^{1}_{1}H$: (P) $^{\circ}e$ $\quad Z = 1$, $\quad M = m_{jezgre} = m_p = 1836\, m_e$

$^{2}_{1}H$: (P)(n) $^{\circ}e$ $\quad Z = 1$, $\quad M_{deut} = m_p + m_n \approx 2 m_p$

$$E_n = -Z^2 \frac{R}{n^2} \quad , \quad R = hc R_H = k_c^2 \frac{m_e c^4}{2\hbar^2}$$

dobivemo iz

$$\mu = \frac{M m_e}{M + m_e} = \frac{m_e}{1 + \frac{m_e}{M}} \approx m_e \quad \text{za } M \gg$$

no sada možemo računati sa punim izrazom

$$\Rightarrow R_{H1} = R \frac{\mu_{H1}}{m_e} \qquad \mu_{H1} = \frac{m_p m_e}{m_p + m_e} = \frac{1836\, m_e^2}{1837\, m_e}$$

$$= R \frac{1836}{1837} \qquad = \frac{1836}{1837} m_e$$

$$R_{H2} = R \frac{\mu_{H2}}{m_e} \qquad \mu_{H2} = \frac{2 m_p m_e}{2 m_p + m_e} = \frac{3672\, m_e^2}{3673\, m_e}$$

$$= R \frac{3672}{3673} \qquad = \frac{3672}{3673} m_e$$

$$E_m - E_n = \Delta E = \frac{hc}{\lambda}$$

$$\Downarrow \quad 4/6$$

$$\frac{1}{\lambda} = \frac{R}{hc}\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

$$\Rightarrow \lambda = \frac{hc}{R} \quad \frac{m^2 n^2}{m^2 - n^2} \qquad 6/4$$

$$\lambda_{H1} = \frac{hc}{R_{H1}} \frac{m^2 n^2}{m^2 - n^2} = \frac{hc}{R\frac{1836}{1837}} \frac{m^2 n^2}{m^2 - n^2}$$

$$= \frac{1837}{1836} \quad \frac{hc}{R} \quad \frac{m^2 n^2}{m^2 - n^2} \qquad 5/4$$

$$= \frac{1837}{1836} \quad \frac{364{,}56\,nm}{4} \quad \frac{2^2 \cdot 3^2}{3^2 - 2^2} \qquad \frac{4 \cdot 9}{9-4} = \frac{36}{5}$$

$$= \frac{1837}{1836} \quad 364{,}56\,nm \cdot \frac{9}{5} = \frac{1837}{1836} \quad 656{,}2\,nm \qquad 1{,}00054$$

$$= \underline{656{,}56\,nm}$$

$$\lambda_{H2} = \frac{hc}{R_{H1}} \frac{m^2 n^2}{m^2 - n^2} = \ldots =$$

$$= \frac{3673}{3672}\, 656{,}2\,nm = \underline{656{,}38\,nm} \qquad 1{,}00027$$

(*)

$\lambda_{max} \cdot T = 2,898 \cdot 10^{-3}\, m\,K$ | WIEN-ov zakon

∼3

- ljudsko tijelo: $T = 36°C \approx 309\,K$

$$\Rightarrow \lambda_{max} \approx \frac{3 \cdot 10^{-3}\, m\,K}{3 \cdot 10^{2}\, K} = 1 \cdot 10^{-5}\, m$$

$$= 10\,\mu m$$

- ugorska navoja: $T = 1500\,K$

$$\Rightarrow \lambda_{max} \approx \frac{3 \cdot 10^{-3}\, m\,K}{1,5 \cdot 10^{3}\, K} = 2 \cdot 10^{-6}\, m$$

$$= 2\,\mu m$$

- žarulja „topla bijela": $T = 3000\,K$

$$\Rightarrow \lambda_{max} \approx \frac{3 \cdot 10^{-3}\, m\,K}{3 \cdot 10^{3}\, K} = 10^{-6}\, m$$

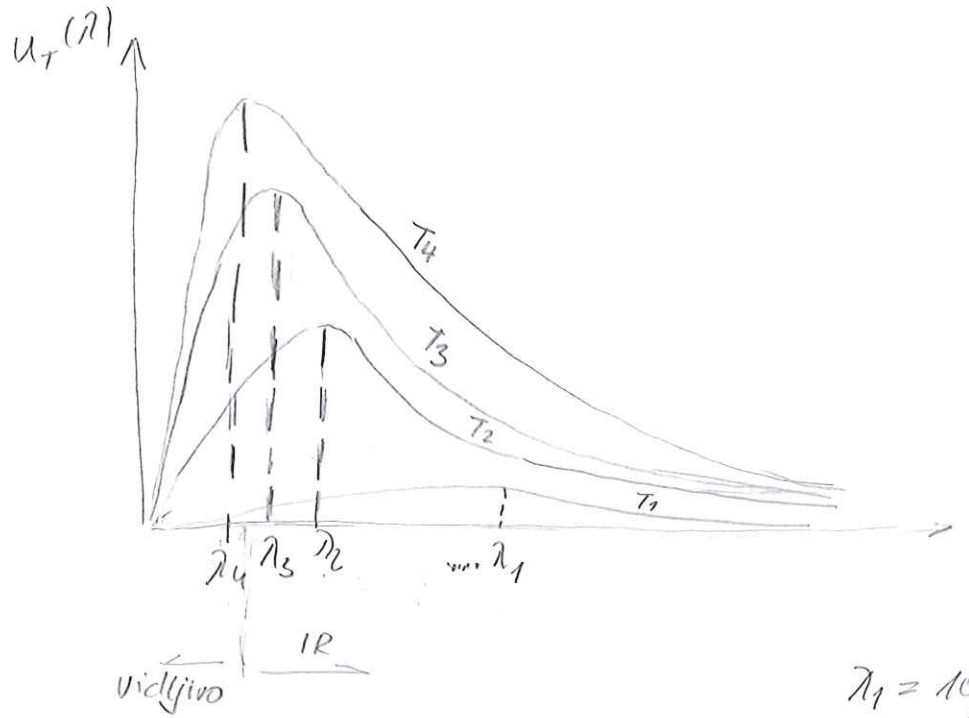
$$= 1\,\mu m$$

- žarulja „hladna bijela": $T = 4500\,K$

$$\Rightarrow \lambda_{max} \approx \frac{3 \cdot 10^{-3}\, m\,K}{4,5 \cdot 10^{3}\, K} = \frac{2}{3} \cdot 10^{-6}\, m$$

$$\approx 0,6\,\mu m = 600\,nm$$

→



$T_1 < T_2 < T_3 < T_4$

$\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4$

$\lambda_1 = 10\,\mu m$ (Gradsko tijelo)

$\lambda_2 = 2\,\mu m$ (log. vatre)

$\lambda_3 = 1\,\mu m$ (žarulja topla bijela)

$\lambda_4 = 0.6\,\mu m$ (žarulja hladno bijela)

Izračunate valne duljine $\lambda_1 = 10\,\mu m$, $\lambda_2 = 2\,\mu m$ i $\lambda_3 = 1\,\mu m$ se nalaze u IR području, a $\lambda_4 = 0.6\,\mu m = 600\,nm$ u vidljivom dijelu spektra.

Gradsko tijelo: $\lambda_{max} = \lambda_1 = 10\,\mu m$

najviše zrači u IR području

log. vatre: $\lambda_{max} = \lambda_2 = 2\,\mu m$

najviše zrači u IR području, ali ipak i u vidljivom dio (dolvo žuto, slabo osvjetljava)

žarulja topla bijela $\lambda_{max} = \lambda_3 = 1\,\mu m$

IR ali dobar dio i u vidljivom

hladno bijela $\lambda_{max} = \lambda_4 = 0.6\,\mu m = 600\,nm$ vidljivo, ali i IR

(*)

a) fotoefekt
COMPTONOVO raspršenje } dovoli do pojma čestične prirode fotona

b) de BROGLIE-ova hipoteza
⇓
DAVISSON-GERMER eksperiment } ⇐ valna priroda materije

c) Princip komplementarnosti:

Valna i čestična priroda materije se ne mogu uočiti u istom trenutku jako jedno bez gubitka uzeti zajedno omogućuju potpuni uvid u prirodu materije.

(*) $\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi(r) = E\,\psi(r)$

a) vremenski neodvisna SCH. jed.

b) SCHRÖDINGER-ova jednadžba za stacionarna stanja