FOTOEFEKT in RENTGENSKA SVETLOBA

1. Svetilka seva svetlobo moči 2 W z valovno dolžino 0,65 μm. Koliko fotonov oddaja svetilka vsako sekundo? ($6{,}5\cdot10^{18}$)

2. Koliko elektronov v sekundi lahko največ izbije iz 1 cm^2 katode enobarvni svetlobni tok z gostoto 10^{-12} W/m^2, če meri izstopno delo 2,3 eV in valovna dolžina svetlobe 500 nm? Koliko pa, če meri valovna dolžina 600 nm?

3. Koliko fotonov pade vsako sekundo v zenico s premerom 5 mm, ki je 1 km od svetilke, ki seva 1 W svetlobe z valovno dolžino 600 nm? Absorpcijski koeficient svetlobe v zraku je 10^{-3} m^{-1}.

4. Koliko fotonov vsako sekundo izseva helij-neonski laser z močjo 1 mW, ki oddaja svetlobo z valovnima dolžinama 543 nm in 633 nm? Predpostavi, da laser seva enako število obeh vrst fotonov?

$$P = W_1\, dN_1/dt + W_2\, dN_2/dt = dN/dt\,(W_1 + W_2) = dN/dt\,(hc/\lambda_1 + hc/\lambda_2) \rightarrow$$
$$dN/dt = P / hc(1/\lambda_1 + 1/\lambda_2) = P\,\lambda_1\,\lambda_2 / hc\,(\lambda_1 + \lambda_2) = 1{,}5\cdot10^{15} \text{ fotonov / s}$$

5. Neko kovino osvetlimo s svetlobo valovne dolžine 590 nm. Izbite elektrone ustavimo z zaporno napetostjo 0,2 V.

a) Kolikšna sta izstopno delo in mejna frekvenca za fotoefekt na tej kovini?
b) S kolikšno zaporno napetostjo ustavimo elektrone, če kovino osvetlimo s svetlobo valovne dolžine 400 nm?

6. Za koliko moramo spremeniti zaporno napetost na fotocelici, če spremenimo valovno dolžino svetlobe, ki pada na fotocelico, od 400 nm na 360 nm?

7. Rentgensko cev za slikanje kosti napajamo s 50 kV. Oceni največjo hitrost elektronov, preden zadenejo anodo? Kolikšna je najmanjša valovna dolžina rentgenskega spektra nastale svetlobe? Masa elektrona je $9{,}1\cdot10^{-31}$ kg. ($v=1{,}3\cdot10^{8}$ m/s, $2{,}48\cdot10^{-11}$ m)

8. Rentgenska cev je priključena na 100 kV. Na anodo pada curek elektronov, ki predstavlja tok 10 mA. Anodo hladimo z vodo. Kolikšen mora biti masni tok hladilne vode, da se ne segreje za več kot 5 °C? Predpostavimo, da se vsa kinetična energija na anodo vpadlih elektronov pretvori v toploto.

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1.

$P_S = 2\,W$

$\lambda = 0{,}65\,\mu m$

$\frac{N}{t}$ } št. fotonov na 1 s = ?

→ neka moč na časovno enoto

$$P_{sv} = \frac{W}{t} = \frac{N \cdot W_f}{t} \Rightarrow P_{sv} = \frac{Nhc}{t\lambda}$$

$$W_f = h \cdot \nu = \frac{h \cdot c}{\lambda}$$

$$W = \frac{J}{s}$$

$$P_{sv} t \lambda = Nhc$$

$$\frac{N}{t} = \frac{P_{sv}\lambda}{hc}$$

$$\frac{N}{t} = \frac{2\,W \cdot 0{,}65 \cdot 10^{-6}\,m}{6{,}6260755\,Js \cdot 299792458\,\frac{m}{s}} = \boxed{6{,}54 \cdot 10^{18}\,s^{-1}}$$

↓ fotonov na s

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2.

$S_1 = 1\,cm^2 = 1\cdot10^{-4}\,m^2$

$j = 1\cdot10^{-12}\,\frac{W}{m^2}$

$A_i = 2{,}3\,eV$

$\lambda_1 = 500\,nm$

$\lambda_2 = 600\,nm$

$\frac{N}{t} = ?$ mi: λ_1, λ_2

$j = \frac{P}{S} \Rightarrow P = j\cdot S = 1\cdot10^{-12}\,\frac{W}{m^2}\cdot 1\cdot10^{-4}\,m^2$

$P = 1\cdot10^{-16}\,W$

$P = \frac{W}{t}$

$P = j\cdot S$

$\frac{W}{t} = j\cdot S \Rightarrow \frac{Nhc}{t\lambda} = j\cdot S$

$W = N\cdot W_f$

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

$\Rightarrow \frac{N}{t} = \frac{j\cdot S\cdot\lambda_{1,2}}{hc}$

$\frac{N}{t} = \frac{1\cdot10^{-12}\,\frac{W}{m^2}\cdot1\cdot10^{-4}\,m^2\cdot500\cdot10^{-9}\,m}{6{,}6260755\cdot10^{-34}\,Js\cdot299792458\,\frac{m}{s}}$

$\frac{\frac{J}{s}}{\ldots} \quad \frac{\frac{W}{m^2}\cdot m^2\cdot m}{Js\cdot\frac{m}{s}} = s^{-1}$

$\frac{N}{t} = \boxed{251{,}705\;s^{-1}}$

Meja da se pride do fotoelektričnega pojava je: $\boxed{A_i = h\cdot\nu = \frac{hc}{\lambda} = W_f}$

$W_{f1} = \frac{hc}{\lambda_1} = \boxed{2{,}47968\,eV} > A_i$ ✓ !

$W_{f2} = \frac{hc}{\lambda_2} = \boxed{2{,}0664\,eV} < A_i$!

✗ ni fotoelektričnega pojava!

$h\cdot c = 1{,}9864474\cdot10^{-25}\,Jm$

$1\,eV = 1{,}60217733\cdot10^{-19}\,J$

$\div \Rightarrow \boxed{hc = 1{,}239842\cdot10^{-6}\,eVm}$

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(3.)

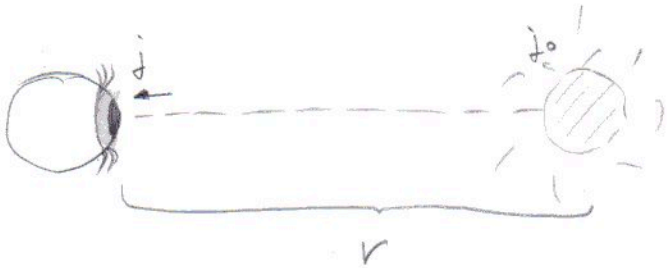
$P_S = 1\,W$

$r = 1000\,m$

$2r_z = 5\,mm$

$\lambda = 600 \cdot 10^{-9}\,m$

$\mu = 1 \cdot 10^{-3}\,m^{-1}$



$$S_z = \pi r_z^2 = \pi \cdot (2{,}5 \cdot 10^{-3}\,m)^2$$

$$\boxed{S_z = 1{,}96 \cdot 10^{-5}\,m^2}$$

$$P_z = j \cdot S_z \qquad j = \frac{P}{4\pi r^2} \cdot e^{-\mu r}$$

Φ - fotonov $\quad \frac{W}{t} = j \cdot S_z$

$$\frac{N \cdot W_f}{t} = \frac{P}{4\pi r^2} \cdot e^{-\mu r} \cdot S_z$$

$$\frac{N}{t} = \frac{P \cdot e^{-\mu r} \cdot S_z}{4\pi r^2 \cdot W_f} = \frac{\lambda \cdot P \cdot e^{-\mu r} \cdot S_z}{4\pi r^2 \cdot h \cdot c}$$

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

$$\frac{N}{t} = \frac{600 \cdot 10^{-9}\,m \cdot e^{-1 \cdot 10^{-3}\,m^{-1} \cdot 1000\,m} \cdot 1\,\frac{J}{s} \cdot 1{,}96 \cdot 10^{-5}\,m^2}{4 \cdot \pi \cdot (1000\,m)^2 \cdot 6{,}62607\,55 \cdot 10^{-34}\,J\,s \cdot 299\,792\,458\,\frac{m}{s}}$$

$$\frac{N}{t} = 1\,733\,109{,}061\,s^{-1} = \boxed{1{,}733 \cdot 10^6\,s^{-1}}$$

$$\frac{m \cdot \frac{J}{s} \cdot m^2}{m^2 \cdot J \cdot \frac{m}{s}} = s^{-1}\ \checkmark$$

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4.

$P_{sl} = 1\ mW = 1 \cdot 10^{-3}\ W$

$\lambda_1 = 543 \cdot 10^{-9}\ m$

$\lambda_2 = 633 \cdot 10^{-9}\ m$

$$P_s = \frac{W}{t} = \frac{N \cdot W_f}{t} = \frac{N \cdot h \cdot c}{t \lambda}$$

$$P_s = \frac{N h c}{t \lambda} \Rightarrow \frac{N}{t} = \frac{P_s \lambda}{hc}$$

$$P_{sl} = \frac{N h c}{t \lambda_1} + \frac{N h c}{t \lambda_2} \Rightarrow \frac{N}{t} = \frac{P_{sl}}{\frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}} = \frac{P_{sl}}{\frac{hc(\lambda_2 + \lambda_1)}{\lambda_1 \lambda_2}}$$

$$\frac{N}{t} = \frac{P_{sl} \lambda_1 \lambda_2}{hc(\lambda_2 + \lambda_1)} = \frac{1 \cdot 10^{-3}\ W \cdot 543 \cdot 10^{-9}\ m \cdot 633 \cdot 10^{-9}\ m}{6{,}6260755 \cdot 10^{-34}\ J\,s \cdot 299792458\ \frac{m}{s} \cdot ((543+633) \cdot 10^{-9})}$$

$$\frac{N}{t} = \boxed{1{,}47136 \cdot 10^{15}\ s^{-1}}$$

$$\frac{\frac{J}{s} \cdot m^2}{J s \cdot \frac{m}{s} \cdot m} = s^{-1}$$

5.

$\lambda = 590\ nm = 590 \cdot 10^{-9}\ m$

$U_z = 0{,}2\ V$

a) A_i, γ_{mejna} = ?

b) U_z = ? če je $\lambda_2 = 400 \cdot 10^{-9}\ m$

a) $W_f = A_i + W_k$ $\qquad W_k = eU_z$

$A_i = W_f - eU_z$ $\qquad W_f = \frac{hc}{\lambda}$

$$A_i = \frac{hc}{\lambda} - eU_z$$

$hc = 1{,}98644746 \cdot 10^{-25}\ J\,m$

$1\ eV = 1{,}602177733 \cdot 10^{-19}\ J$

$hc = 1{,}239842 \cdot 10^{-6}\ eV\,m$

$$A_i = \frac{1{,}239842 \cdot 10^{-6}\ eV\,m}{590 \cdot 10^{-9}\ m} - e \cdot 0{,}2\ V$$

$A_i = \boxed{1{,}9014\ eV}$ – izstopno delo

Za drugi fotoefekt:

$A_i = W_f \Rightarrow A_i = h \cdot \gamma_0 \Rightarrow \gamma_0 = \frac{A_i}{h} = \frac{3{,}0464 \cdot 10^{-19}\ J}{6{,}6260755 \cdot 10^{-34}\ J\,s} = \boxed{4{,}5976 \cdot 10^{14}\ Hz}$

$$A_i = \frac{1{,}602177733 \cdot 10^{-19}\ J \cdot 1{,}9014\ eV}{1\ eV}$$

$A_i = 3{,}046 \cdot 10^{-19}\ J$

b) → drugi list

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5. b)

$\lambda = 400\ nm$

$U_z = ?$

$eU_z = W_k$

$W_f = A_i + W_k$

$W_f = A_i + eU_z$

$W_f = h\nu = \frac{hc}{\lambda}$

$$\frac{hc}{\lambda} = A_i + eU_z$$

$$U_z = \frac{1}{e} \cdot \left(\frac{hc}{\lambda} - A_i \right)$$

$$U_z = \frac{1}{e} \cdot \left(\frac{h[Js] \cdot c[\frac{m}{s}]}{400 \cdot 10^{-9}\ m} - 1{,}9014\ eV \right)$$

eV

$hc = 1{,}986447 \cdot 10^{-25}\ Jm$

$eV = 1{,}602177 33 \cdot 10^{-19}\ J$ $\Big\} \div \Rightarrow \underset{[eVm]}{hc} = 1{,}239842 \cdot 10^{-6}\ eVm$

$$U_z = \frac{\frac{1{,}23984 \cdot 10^{-6}\ \not{eV}\not{m}}{400 \cdot 10^{-9}\ \not{m}} - 1{,}9014\ \not{eV}}{\not{e}} = \boxed{1{,}198\ V}$$

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6.)

$\Delta U_z = ?$

$\lambda_1 = 400 \cdot 10^{-9}\ m$

$\lambda_2 = 360 \cdot 10^{-9}\ m$

$\Delta U_z = U_{z1} - U_{z2}$

$eU_z = W_k$

$W_f = h\nu = \frac{hc}{\lambda}$

$W_f = A_i + W_k$

$\frac{hc}{\lambda} = A_i + eU_z$

$U_z = \frac{1}{e}\left(\frac{hc}{\lambda} - A_i\right)$

$\Delta U_z = U_{z1} - U_{z2}$ ← $U_{z2} - U_{z1}$ ✓

$\Delta U_z = \frac{1}{e}\left(\left(\frac{hc}{\lambda_1} - A_i\right) - \left(\frac{hc}{\lambda_2} - A_i\right)\right)$

$\Delta U_z = \frac{1}{e}\left(\frac{hc}{\lambda_1} - \cancel{A_1} - \frac{hc}{\lambda_2} + \cancel{A_1}\right)$

$\Delta U_z = \frac{1}{e}\left(\frac{hc(\lambda_2 - \lambda_1)}{\lambda_1 \lambda_2}\right)$

zanemi

$\Delta U_z = \frac{1}{\cancel{e}}\left(\frac{hc[\cancel{eV}](360-400)\cdot 10^{-9}\,\cancel{m})}{400\cdot 10^{-9}\,\cancel{m}\cdot 360\cdot 10^{-9}\,\cancel{m}}\right)$

$\Delta U_z = 0{,}344\ V$

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(7.)

$U_p = 50\ kV$

$m_e = 9{,}1 \cdot 10^{-31}\ kg$

$\lambda_{min}, v = ?$

za manje brzine do sv. brzine

$W_k = eU_p = \frac{mv^2}{2}$

$eV = 1{,}60217733 \cdot 10^{-19}\ J$

⇓

$v = \sqrt{\frac{2eU_p}{m}} = \sqrt{\frac{2 \cdot 50 \cdot 10^3\ eV}{9{,}1 \cdot 10^{-31}\ kg}}$

$v = 1{,}3626 \cdot 10^8\ m/s$

→ ecate

$\sqrt{\frac{J}{kg}}$

$\sqrt{\frac{\frac{kg \cdot m^2}{s^2}}{\frac{kg}{1}}} = m/s$ ✓

$W_{f\,max} = W_{ke}$

$eU_p = \frac{hc}{\lambda_{min}}$ ko je λ_{min} je ν_{max}.

$\lambda_{min} = \frac{hc[eVm]}{eU_p} = \frac{1{,}23 \cdot 10^{-6}\ eVm}{50 \cdot 10^3\ eV} = 2{,}4797 \cdot 10^{-11}\ m$

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(8.)

$U_p = 100\,kV = 100 \cdot 10^3\,V$

Energija vsakega elektrona: $W_k = eU_p$

$I = 10\,mA$

$\Delta T = 5\,°C$

$P = U \cdot I$

$W_k = Q$

Moč, ki bo na anodi: $P = \frac{W_k \cdot e}{t} = \frac{eU}{t}$

$\frac{m}{t} = ?$

$I = \frac{e}{t}$

Toplotna moč, ki jo odvaja voda:

$P = \frac{Q}{t} = \frac{m c \Delta T}{t}$

$U \cdot I = \frac{m c \Delta T}{t}$

$\frac{m}{t} = \frac{UI}{c \Delta T}$

$\frac{m}{t} = \frac{100 \cdot 10^3\,V \cdot 10 \cdot 10^{-3}\,A}{299 \cdot 10^3 \frac{J}{kg \cdot K} \cdot 5\,°C}$

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