# **Exam Physics of Modern Technology** (WBPH027-05)

Friday 27 January 2023, 8:30 – 10:30

## MODEL ANSWERS

on the parts 1) Guimarães, 2) Van der Wal, 3) Giuntoli

PMT - Guimarães Jan 2023

(a) $E_\lambda = 100\,keV$ $\lambda = 1.22/\sqrt{E}$

a.1)

$r = \alpha^3 C_s = \dfrac{0.61\lambda}{\alpha} \Rightarrow 0.61\lambda = \alpha^4 C_s$

$\alpha = (0.61)^{1/4} \lambda^{1/4} C_s^{-1/4}$

$$\boxed{r = (0.61)^{3/4} \lambda^{3/4} C_s^{1/4}}$$

a.2) $C_s = 1\,mm = 10^{-3}\,m$ $\lambda = \dfrac{1.22}{\sqrt{E}} \Rightarrow \lambda = 0.00386\,nm$

$r = 0.69 \times (3.86\times10^{-12})^{3/4} \times (10^{-3})^{1/4}$

$r = 3.38\times10^{-10}\,m \Rightarrow \boxed{r = 0.338\,nm}$

b) $E = 100\,MeV$

$$E = \frac{mc^2}{\sqrt{1-(v/c)^2}} \Rightarrow \sqrt{1-\left(\frac{v}{c}\right)^2} = \frac{mc^2}{E} \Rightarrow 1-\left(\frac{v}{c}\right)^2 = \left(\frac{mc^2}{E}\right)^2$$

$$\boxed{\frac{v}{c} = \sqrt{1-\left(\frac{mc^2}{E}\right)^2}}$$

$$E = 100\,MeV + m_p c^2 \Rightarrow E = 100\times10^{6}\times 1.602\times10^{-19}\,J + \left(1.67\times10^{-27}\,kg \times \left(2.998\times10^{8}\,\tfrac{m}{s}\right)^2\right)$$

$$\boxed{\frac{v}{c} = 0.428}$$

c.1) $A = 100 \times 100\ nm^2$

$n = 5 \times 10^{16} / m^2$

$m = 9.11 \times 10^{-31}\ kg$

$W_{1b} = n \cdot A \cdot m \Rightarrow W_{1b} = 5 \times 10^{16} \frac{1}{m^2} \times 10^{-14}\ m^2 \times 9.11 \times 10^{-31}\ kg$

$W_{1b} = 4.555 \times 10^{-28}\ kg/bit$

8 bits/byte $\times 10^9$ bytes/GB

$8 \times 10^9$ bits/GB

$$\boxed{W_{1GB} = 3.644 \times 10^{-18}\ kg}$$

C.2) $J_e = A_i \exp[-b_i]$

$A_i = \frac{V_i}{4\pi \hbar t^2}$

$b_i = \frac{t}{\hbar}\sqrt{8 m V_i}$

$A = 4.03 \times 10^{31} / m^2 s$

$b = 53.27$

$$\boxed{J = 2.956 \times 10^{8} / m^2 s}$$

C.3) $t = \frac{n}{J} \Rightarrow t = 5 \times 10^{16} \frac{1}{m^2} \frac{1}{2.956 \times 10^{8}}\ m^2 s$

$$\boxed{t = 1.69 \times 10^{8}\ s}$$

Physics of Modern Technology
PART VAN DER WAL
Exam 27-1-2023

2.1a) Upon population inversion, more than 50% of the electrons are in level 2. For lasing they make a transition from 2 to 1, but the fast pumping and rapid relaxation 3 to 2 keeps most in 2 on average

2.1b) Electrons should be ready to make a transition from 2 to 1, when stimulated by an existing resonant optical field. This is stimulated emission. If there are more electrons in 1 than 2, this does not occur, then there is mainly absorption related to a transition 1 to 2.

2.1c) No, this is not possible. If the laser gets pumped harder, the populations on 1 and 2 will get closer to 50/50. But the ~~pump~~ then drives both $1 \rightarrow 2$ and $2 \rightarrow 1$, so you will not get more than 50% in 2.

2.2a) The LED functions well when electrons flow in via the n-type layer, and out via the p-type layer ⇒ The electron flow must be from left to right ⇒ The electrical current must be from right to left.

2.2 b) $\frac{dn(t)}{dt} = -\frac{1}{\tau} n(t)$ ⇒ Look for a solution where $\frac{d}{dt}$ gives the function itself times a constant. ⇒ solutions are in the form

$e^{ct}$, and $c = -\frac{1}{\tau}$.

Filling in $n(t) = n(0)\, e^{-\frac{1}{\tau} \cdot t}$ indeed shows that

$$\frac{dn(t)}{dt} = -\frac{1}{\tau} n(t)$$

2.2c) $n(t) = 0{,}05 \cdot n(0) \Rightarrow e^{-\frac{t}{\tau}} = 0{,}05 \Rightarrow$

$-\frac{t}{\tau} = \ln(0{,}05) \Rightarrow t = -\ln(0{,}05) \cdot \tau$

⇒ filling in the numbers gives $t = 59.9$ ns

2.2 d) $\frac{dn(t)}{dt} = 0 \Rightarrow n(t) = Q \cdot \tau$

$I = mA \Rightarrow Q = \frac{I}{e}$ electrons per second. ⇒

$$N_{\substack{\text{photons}\\ \text{per second}}} = Q \cdot \tau = \frac{I}{e} \cdot \tau$$

$$= \frac{1 \cdot 10^{-3}}{1{,}602 \cdot 10^{-19}} \cdot 20 \cdot 10^{-9} = 1{,}25 \cdot 10^{8} \text{ photons/sec}$$

Alternative



2.2b) Fill in into $\frac{dn(t)}{dt}$ the expression

$$n(t) = n(0)\, e^{-t/\tau} \Rightarrow$$

$$\frac{d}{dt}\left(n(0)\, e^{-t/\tau}\right) = -\frac{1}{\tau} \cdot n(0) \cdot e^{-t/\tau} = -\frac{1}{\tau}\, n(t)$$

q.e.d.

**Exam answers - Part Giuntoli - 27/01/2023**

a1) Cross model: $\eta_{shear} = \frac{\eta_{eq}}{1+(\lambda\dot{\gamma})^{1-n}}$

Solve for $\eta_{eq}$: $100\,\text{Poise} = \frac{\eta_{eq}}{1+(1\cdot 81)^{0.5}} = \frac{\eta_{eq}}{1+9} = \frac{\eta_{eq}}{10} \rightarrow \boxed{\eta_{eq} = 1000\ \text{Poise}}$

a2) VFT equation: $\eta_{eq}(T) = \eta_0 \cdot e^{\frac{B}{T-T_{VF}}} \rightarrow \ln\left[\frac{\eta_{eq}}{\eta_0}\right] = \frac{B}{T-T_{VF}}$

solve for T: $\ln\left[\frac{1000}{6,738}\right] = \frac{1000K}{T-300K} \rightarrow T - 300K = \frac{1000K}{\ln\left[\frac{1000}{6,738}\right]}$

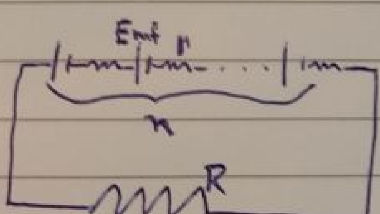
$\rightarrow T = 300K + \frac{1000K}{5} = \boxed{500K}$

b1) $\bar{Q} = \int_{298K}^{500K} 7,444\cdot 10^{-4}\cdot T\,dT = 7,444\cdot 10^{-4}\cdot \frac{T^2}{2}\Big|_{298K}^{500K} =$

$= \frac{7,444\cdot 10^{-4}}{2}\left[500^2 - 298^2\right] = \boxed{60\ J}$

b2) Power is heat per unit time, so in time t $Q = P\cdot t$

→ solve for P: $\bar{P} = \frac{\bar{Q}}{t} = \frac{60J}{2s} = \boxed{30\ J/s}$ or 30 W

c1) 


c2) $P = I^2 R \rightarrow I = \sqrt{\frac{\bar{P}}{R}} = \sqrt{\frac{30W}{7.5\Omega}} = \boxed{2A}$, $V_{cart} = IR = \boxed{15V}$

c3) It is also true that $V_{cart} = n\left[E_{mf} - Ir\right] \rightarrow n = \frac{V_{cart}}{E_{mf} - Ir} =$

$= \frac{15V}{1.5V - (2\cdot 0,5)V} = \frac{15V}{0.5V} = \boxed{30}$ batteries needed.

c4) The same current goes through all batteries: $\frac{C}{I} = \frac{2000\,mAh}{2A} = \boxed{1\,\text{hour}}$ of autonomy.