Physics 2250: Problem Set VII

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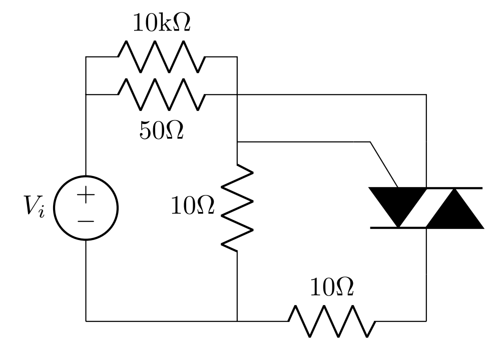
Problem 1. Consider the circuit below containing an ac voltage source, $V_i = \cos\left(\frac{2\pi}{T}t\right)$ V, and a triac device with a trigger voltage of $V_t = \pm 1$V and holding currentthreshold of $I_H \approx 100\mu$A. $R_1 = 50\Omega, R_2 = 10\text{k}\Omega, R_3 = 10\Omega, R_L = 10\Omega$.



Solution 1.

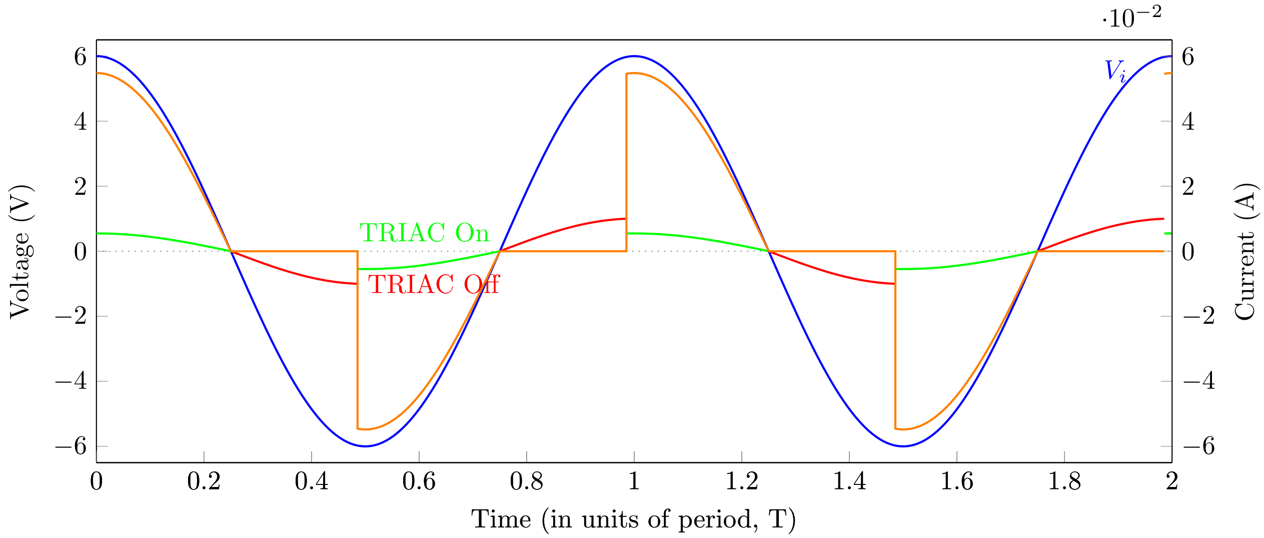
$$V_T = V_i - I_i \left(R_1^{-1} + R_2^{-1}\right)^{-1}$$

$$I_L = I_i \left(\frac{R_3}{R_3 + R_L}\right)$$

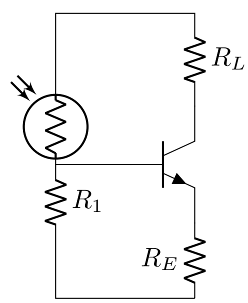
$$I_{ion} = \frac{V_i}{\left(R_1^{-1} + R_2^{-1}\right)^{-1} + \left(R_L^{-1} + R_3^{-1}\right)^{-1}} = \frac{V_i}{\left(R_1^{-1} + R_2^{-1}\right)^{-1} + 5\Omega}$$

$$I_{ioff} = \frac{V_i}{\left(R_1^{-1} + R_2^{-1}\right)^{-1} + R_3} = \frac{V_i}{\left(R_1^{-1} + R_2^{-1}\right)^{-1} + 10\Omega}$$

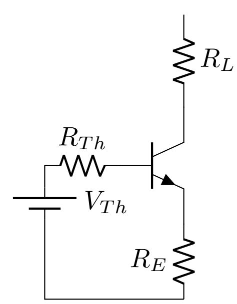
$\cos(2\pi t)$ will start high, eg at 6V which logically means the device will turn on immediately which means a current of $\frac{V_i}{\left(R_1^{-1}+R_2^{-1}\right)^{-1}+5\Omega}\left(\frac{R_3}{R_3+R_L}\right) = \frac{6\text{V}}{2\cdot(49.75\Omega+5\Omega)} = \frac{4}{73}$A. This (time-variant) current will continue to flow until $\cos(2\pi t) \approx 0$ at which point the triac will shut off as both current and gate voltage have dropped below their thresholds. The triac will next reactivate when $6\cos(2\pi t)\left(1 - \frac{\left(R_1^{-1}+R_2^{-1}\right)^{-1}}{\left(R_1^{-1}+R_2^{-1}\right)^{-1}+10\Omega}\right) = -1$V and will remain active until the current again reaches ≈ 0A. Then, the triac will reactivate at $V_t = 1$V and the cycle repeats from there.



Problem 2. The circuit shown below controls the brightness of a smartphone screen (via R_L). It works such that when the photoconductive cell detects a high level of ambient light (e.g., when you are out in the sun) the base-emitter junction of the transistor becomes forward biased and automatically increases the brightness of the screen via power expended in R_L. The turning on/off only depends on how the resistance of the photoconductive cell (R_C) varies with the amount of light striking it. Notes: The voltage supply is $V_{CC} = 20\text{V}$; The resistors are: $R = 10\text{k}\Omega$, $R_L = 1\text{k}\Omega$, $R_E = 2\text{k}\Omega$; and the transistor has a forward-active working point voltage of $V_{CE} = 6\text{V}$ and gain $\beta = 50$.



Solution 2.
a) We can find the Thévenin equivalent of the right circuit with $R_{Th} = R_b = \frac{R_x R_1}{R_x + R_1}$ (I used R_x because I kept confusing C and L when writing this on paper) and $V_{Th} = V_b = \frac{V_{CC} R_1}{R_1 + R_x}$.



From there we can use KVL on the bottom loop $V_{CC}\frac{R_1}{R_1+R_x} - I_b\frac{R_x R_1}{R_x+R_1} - 0.7 - (1+\beta)\, I_b R_E \implies I_b = \dfrac{0.7 - \frac{V_{CC} R_1}{R_1+R_x}}{-\frac{R_x R_1}{R_x+R_1} - (1+\beta)\, R_E}$. Now, we are looking for when the transistor activates and allows current flow through R_L. This will occur when $V_b + 0.7\text{V} = V_e$ whent the transistor is just barely active. I think (my understanding of transistors is still very poor) that $V_e = V_{CC} - I_C R_L - V_{CE}$ so under that slightly educated assumption

$$\begin{aligned}
&\frac{V_{CC}R_1}{R_1+R_x} + 0.7\text{V} = V_{CC} - I_C R_L - V_{CE} \\
&\frac{20R_1}{R_1+R_x} + 0.7\text{V} = 20 - \beta I_b R_L - 6 \\
&\frac{20R_1}{R_1+R_x} + 0.7\text{V} = 20 - \beta \frac{0.7 - \frac{V_{CC}R_1}{R_1+R_x}}{-\frac{R_x R_1}{R_x+R_1} - (1+\beta) R_E} R_L - 6 \\
&\frac{20R_1}{R_1+R_x} + 0.7\text{V} = 20 - \beta \frac{0.7 - \frac{V_{CC}R_1}{R_1+R_x}}{-\frac{R_x R_1}{R_x+R_1} - (1+\beta) R_E} R_L - 6 \\
&R_x \approx 11514\Omega
\end{aligned}$$

b) It's difficult to be accurate as all the indicator lines are faded but it looks like the line fits well about a third of the way between 30 and 100 lx and at exactly 3kΩ so $\frac{3\text{k}\Omega - 100\text{k}\Omega}{53\text{lx} - 1\text{lx}} \approx -1865\Omega\,\text{lx}^{-1} \implies \Omega(l) = -1865\Omega\,\text{lx}^{-1} l + 101865\Omega$

Problem 3. Consider the circuit (not) below that uses a K-type thermocouple to measure and control the temperature of a reaction in a beaker. Power expended in the 50Ω load resistor RL is used to heat the reaction beaker. [$V_{cc} = 24$V, $R = 10\Omega$, $R_f = 5\text{k}\Omega$, and the BJT is made is of silicon, with an operating point of $V_{CE} = 6$V, $V_F = 0.7$V, and $\beta = 50$. A K-type thermocouple look-up voltage table is included in the lecture notes]

Solution 3.
a) $P = \frac{V^2}{R} = \frac{(V_{cc} - V_{ce})^2}{R_L} = 3.92\text{W}$
b) Using the lookup table a 22°C temperature coresponds to $V_{ref} = 0.879$mV. The load resistor drops $V_e = (1+\beta) I_b R_l$ and we are looking to have an output from the subtractor op amp configuration that satisfies $V_e = V_b \implies (1+\beta) I_b R_l = \frac{R_f}{R}(V_{TC} - V_{set})$. To find I_b we go from V_{cc} to ground $V_{cc} - V_{ce} - (1+\beta) I_b R_l = 0 \implies I_b = 7.06\text{mA}$

$$\begin{aligned}
&(1+\beta) I_b R_l = \frac{R_f}{R}(V_{TC} - V_{set}) \\
&51 \cdot 7.0588\text{mA} \cdot 50\Omega = \frac{5\text{k}\Omega}{10\Omega}(V_{TC} + 36\text{mV}) \\
&V_{TC} = 0
\end{aligned}$$

c) $V_{lookup} = V_{TC} - V_{ref} = -0.879$mV which doesn't really make any sense at all as when I looked up a bigger table that value coresponds to an output temperature of −22.6687°C which to my understanding of resistance is physically impossible. I've attached my work for this question and the others in case that helps my case here but I cannot seem to figure out getting an answer that makes sense.
d)