Mid-term exam, Electronic Circuits, Spring semester, 2017

April 17, 2017

We have 33 questions. 90 minutes allowed. Write down your answers on the answer sheets. For each question, use the designated answer slot.

Some useful facts are summarized below:

For a resistor, $V = IR$. For a capacitor, $I = C\ dV/dt$. For an inductor, $V = L\ dI/dt$.

A good value for the thermal voltage, V_T, at room temperature is 0.02585 V. You may use an approximate value.

Approximately, $\ln 10 \approx 2.3$.

At a given time, the power dissipation is defined by $P(t) = I(t)V(t)$.

At room temperature, the intrinsic carrier density of silicon, n_i, is 10^{10} /cm^3.

The built-in potential in a pn junction is given by $V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$.

1. Consider a DC case. What is the output voltage?

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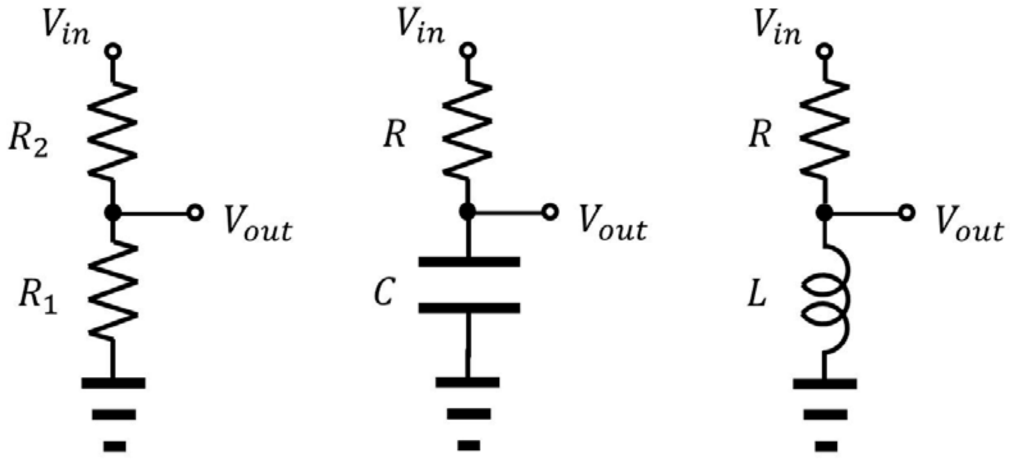
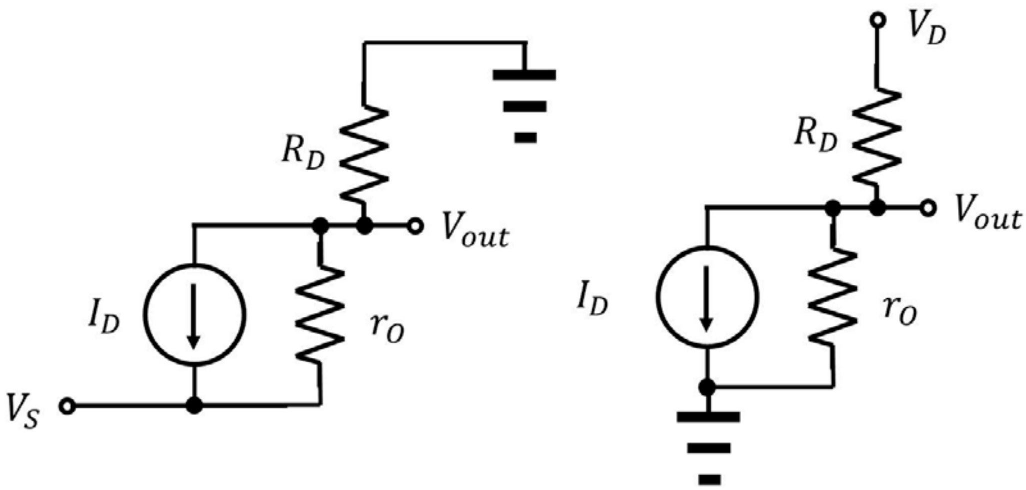


Problem 1. Problem 2. Problem 3.

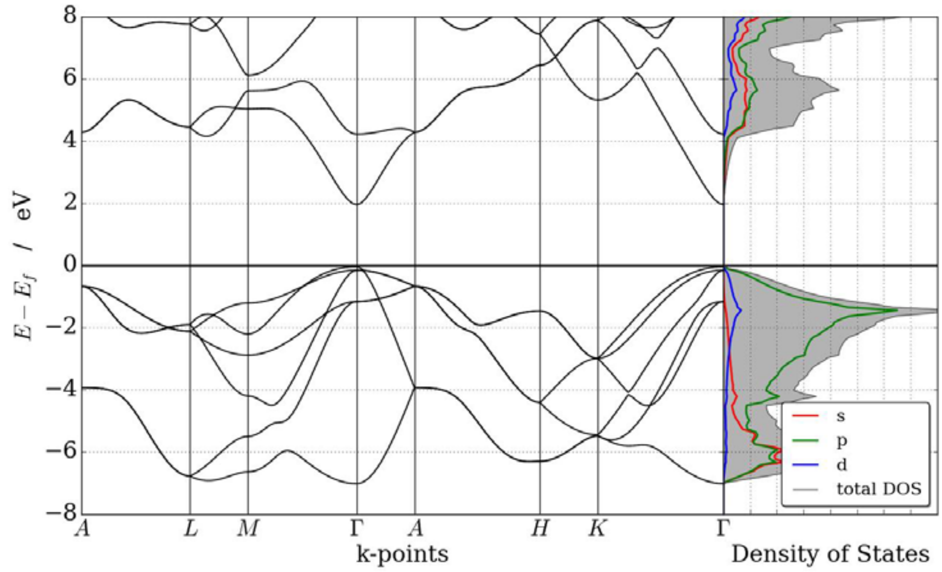
4. By using the Kirchhoff current law, calculate the output voltage as a function of V_S and I_D.

5. By using the Kirchhoff current law, calculate the output voltage as a function of V_D and I_D.



Problem 4. Problem 5.

6. The density-of-states of a certain bulk material is shown. At 0K, states up to 0 eV are completely filled with electrons. Beyond 0 eV, states are completely empty. Write down the estimated value of the bandgap energy.

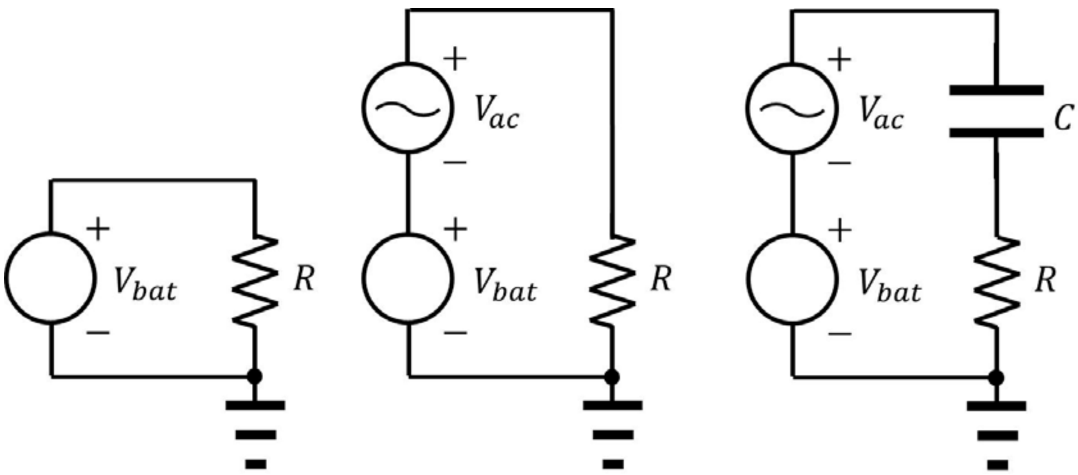


Problem 6.

7. Calculate the power dissipation in the DC battery and the resistor, respectively.

8. Now, in addition to the DC battery voltage, a sinusoidal voltage source is introduced. Its magnitude is V_{ac}. Its frequency is 1 kHz. Calculate the average power dissipation in the resistor during 1 msec.

9. A capacitor is added. Calculate the average power dissipation in the capacitor during 1 msec.



Problem 7. Problem 8. Problem 9.

10. We know that $\mathrm{n} = \mathrm{n_i} \exp\frac{\phi}{V_T}$ and $\mathrm{p} = \mathrm{n_i} \exp\frac{-\phi}{V_T}$ at equilibrium. Here, ϕ is the electrostatic potential. Assume that the net (positively) ionized dopant density is N^+. Using the charge neutrality condition, express the electron and hole concentrations as functions of N^+.

11. Three equations are shown below. From these equations, we can derive an equation for the total current density, $\mathbf{J}_{\mathrm{tot}}$. After defining the total current density, write down a microscopic equation corresponding to the Kirchhoff current law.

$$\nabla \cdot \mathbf{D} = \rho = q(p - n + N^+)$$

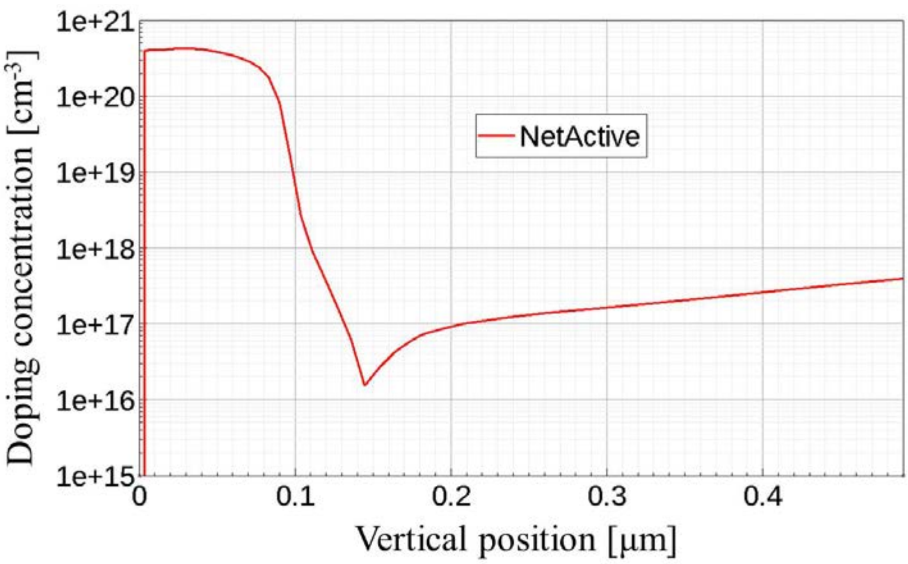
$$\nabla \cdot \mathbf{J}_{\mathrm{n}} = q\frac{\partial n}{\partial t}$$

$$\nabla \cdot \mathbf{J}_{\mathrm{p}} = -q\frac{\partial p}{\partial t}$$

12. At equilibrium, according to the Einstein relation, there is a relation between the mobility and the diffusion constant. At room temperature, the electron mobility is 1000 $\mathrm{cm^2/(V\ sec)}$ and the hole mobility is 400 $\mathrm{cm^2/(V\ sec)}$. Write down the electron/hole diffusion constants. Explicitly show their unit.

13. In the silicon substrate, boron(B) atoms are uniformly doped. Its doping density is 10^{16} $/\mathrm{cm^3}$. Then, what is the expected electron density?

14. Starting from the p-well, arsenic ions are implanted with a dose of $5\text{X}10^{15}$ $/\mathrm{cm^2}$ and an energy of 40 keV. The resultant doping concentration (actually, its absolute value) is drawn. Write down the position of the metallurgical junction.



Problem 14.

15. In the drift-diffusion scheme, the particle current density is written as a sum of the drift current density and the diffusion one. Write down the electron current density, $\mathbf{J}_{\mathrm{n}}$. (Signs are important.)

16. A silicon pn junction employs the acceptor density of $2X10^{16}$ /cm^3 and the donor density of $5X10^{16}$ /cm^3. Determine the built-in potential at room temperature.

17. For a diode, which is forward-biased at 0.3 V, the terminal current is 3.33 pA. When the bias voltage becomes 0.6 V, what is the expected terminal current?

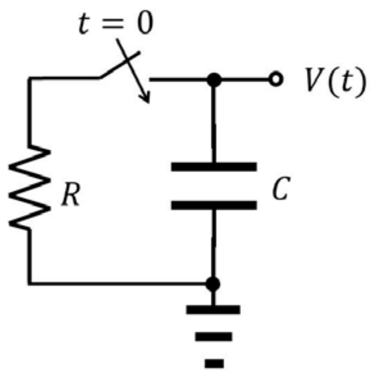
18. In this problem, let us assume that the IV characteristic of a pn diode follows $I_D = I_s \exp\frac{V_D}{V_T}$. When the diode voltage, V_D, is increased to $V_D + \Delta V$, the diode current will be increased, too. Express the incremental current (ΔI) as a function of I_D, V_T, and ΔV.

19. Now, consider the relation between ΔV and ΔI of Problem 18. Since they are a voltage and a current, we can consider a resistance. Such a resistance is called as the small-signal resistance. Using the result of Problem 18, calculate the small-signal resistance of the diode of Problem 17. Bias voltage is 0.3 V.

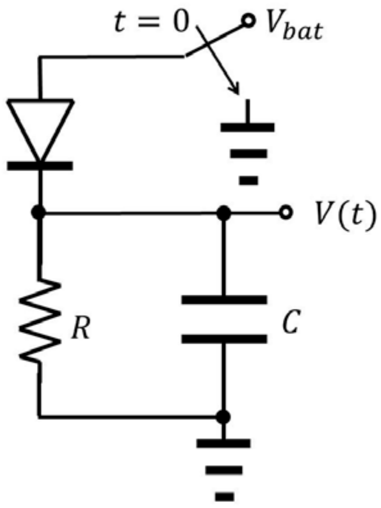
20. Repeat Problem 19 for the bias voltage of 0.6 V.

21. Consider the RC circuit. Initially, the capacitor is charged to $V(t = 0)$. At time $t = 0$, the resistor is connected to the capacitor. By applying the Kirchhoff current law, solve the voltage as a function of time.

22. Initially, the diode is connected to the battery voltage. At time $t = 0$, the resistor is connected to the ground. The voltage required to turn on the diode is $V_{D,on}$. Using the answer of Problem 21, solve the voltage as a function of time.



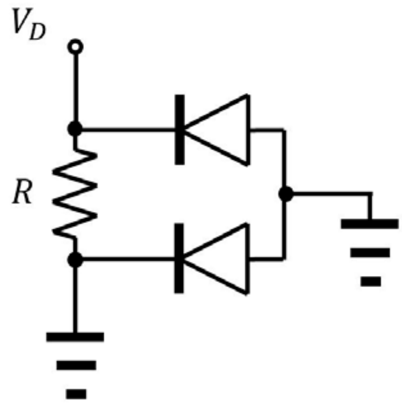
Problem 21.



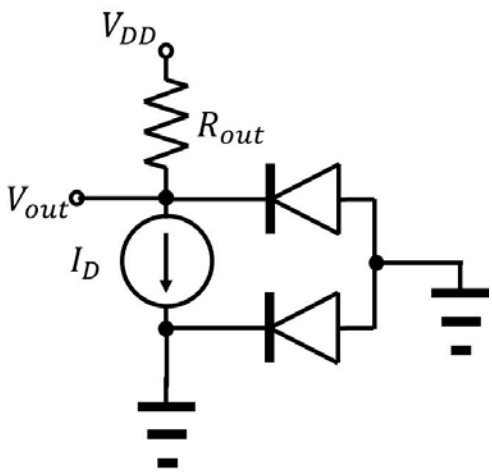
Problem 22.

23. Calculate the resistor current.

24. Instead of a resistor, a current source is introduced. Calculate the output voltage.



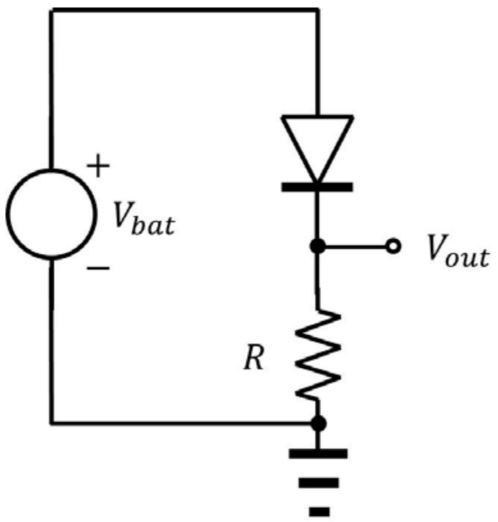
Problem 23.



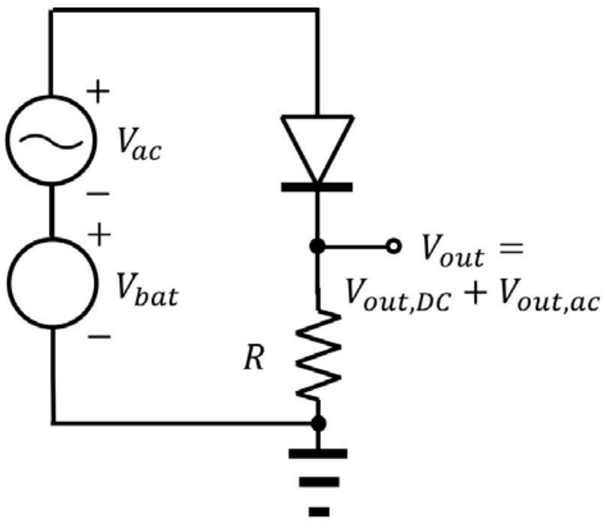
Problem 24.

25. Express the output voltage as a function of V_{bat}. The voltage required to turn on the diode is $V_{D,on}$. Assume that V_{bat} is either sufficiently larger than $V_{D,on}$ or sufficiently smaller.

26. In addition to the DC battery voltage, a sinusoidal voltage source is introduced. Its magnitude is V_{ac}. Its frequency is 1 kHz. Therefore, the output voltage, V_{out}, can be decomposed into two terms, its DC component, $V_{out,DC}$, and its ac component, $V_{out,ac}$. Find out the relation between V_{ac} and the magnitude of $V_{out,ac}$.



Problem 25.



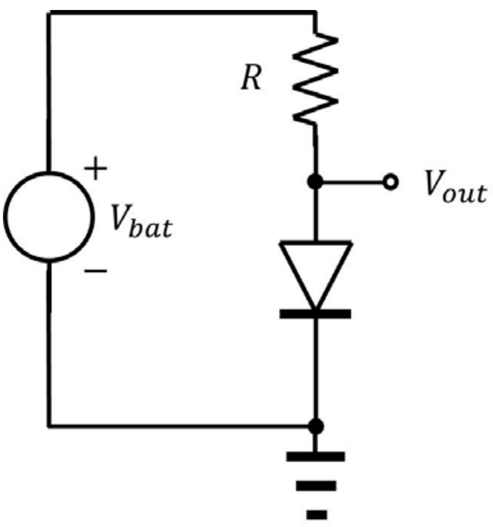
Problem 26.

27. In Problem 26, we implicitly assume that $V_{out,ac}$ is a sinusoidal signal with its frequency of 1 kHz. Under which condition, such an assumption is valid?

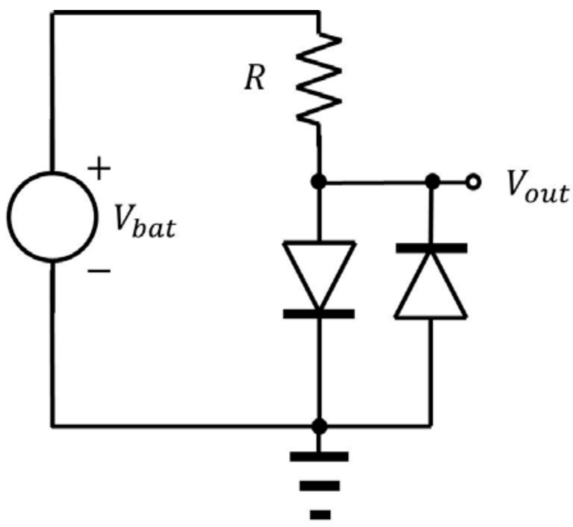
28. In Problem 25, it is assumed that V_{bat} is sufficiently different from $V_{D,on}$. In this problem, such a restriction is removed. By using the Kirchhoff current law, write down the equation for the output voltage. (You don't have to solve it.)

29. The circuit looks quite similar with that in Problem 25. But they are different. Express the output voltage as a function of V_{bat}. The voltage required to turn on the diode is $V_{D,on}$.

30. Now, a diode, whose polarity is reversed, is added. Express the output voltage as a function of V_{bat}. The voltage required to turn on the diode is $V_{D,on}$.



Problem 29.

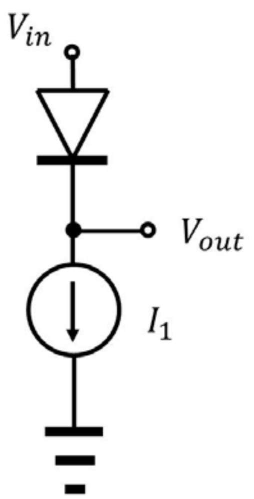


Problem 30.

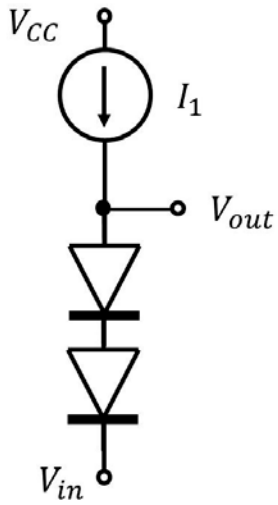
31. Calculate the power dissipation in Problem 29.

32. Consider a DC case. Calculate the output voltage. Let us assume that the magnitude of the current source is sufficiently large to turn on the diode. The voltage required to turn on the diode is $V_{D,on}$.

33. Repeat the Problem 32. Here, V_{CC} is sufficiently large.



Problem 32.



Problem 33.