Captains Tryouts

Detector Building

Tryout Test – 50 minutes

Interlake High School, WA
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Note: for most questions, students must show work for full credit.
§1: Resistance, Voltage, and Temperature

1. [3] How does the resistance of a copper wire change as temperature is increased? Why?
   (1) **Resistance increases**
   (1) **Thermal motion increases with temperature**
   (1) **Increased thermal motion decreases mobility of free electrons**

2. [3] How does the resistance of i-type silicon change as temperature is increased? Why?
   (1) **Resistance decreases**
   (1) **Electron energy increases with increasing temperature**
   (1) **Higher energy electrons are more likely to cross the band gap into the conduction band**

3. Copper has a resistivity of $1.68 \times 10^{-8} \, \Omega \cdot m$ at 20 °C and a temperature coefficient of 0.00404 K$^{-1}$. A 10 cm long copper wire with diameter 2.588 mm is created and put into a circuit where it passes 1.5 A of current. The wire is kept in thermodynamic equilibrium at a temperature of 45 °C.
   a. [1] What is the resistivity of the wire?
      $$\rho = \frac{\rho \cdot 10 \, cm}{n \cdot (0.002588 \, m)^2} = 1.68 \times 10^{-8} \Omega \cdot m$$
   b. [2] What is the resistance of the wire?
      $$R = \frac{\rho \cdot 10 \, cm}{n \cdot (0.002588 \, m)^2} = 3.52 \times 10^{-4} \, \Omega$$
      $$V = IR = 5.27 \times 10^{-4} \, V$$
   c. [1] What is the voltage drop across the wire?

4. [3] Which is a better conductor of electricity: pure water or saltwater? Why?
   (1) **Salt water** is the better conductor
   (1) **Salt water** has ions whereas pure water basically does not (self-ionization is negligible)
   (1) **Ions act as charge carriers and will conduct electricity**.
5. [3] How does the resistance of an AC power line change as AC frequency is increased? Why?

   (i) It increases

   (i) Due to the skin effect (eddy currents)

   (i) Cross-sectional area of the wire effectively decreases, increasing current.

6. Consider the following circuit diagram:

   a. [4] Complete the following table:

      | Circuit Element | Voltage Drop (V) |
      |-----------------|-----------------|
      | R1              | (i) 3           |
      | R2              | (i) 0.6         |
      | R3              | (i) 2.4         |
      | R4              | (o.s) 0         |
      | R5              | (o.s) 0         |

   b. [2] Suppose the voltage source is running low on battery and the voltage it supplies drops below 3 V. Assuming all other factors stay the same, how does the resistance of the circuit change? Why?

      (i) Does not change

      (i) Ohmic resistors' resistance does not depend on voltage.

   c. [2] What is the power dissipated in resistor R2?

      (i) For work, (i) for answer. \[ P = \frac{V^2}{R} = \frac{0.6^2}{25} = 0.0144 \text{ W} \]

7. [2] Two general classes of thermistors are NTC and PTC. What do these acronyms stand for, and how does this affect the dependence of the resistance of the thermistor on temperature?

   (o.s) Negative Temperature Coefficient

   (o.s) Positive

   (o.s) NTCs decrease in resistance as temperature increases

   (o.s) PTCs increase in resistance as temperature increases
8. [3] Draw the electronic symbol for a standard LED, and indicate the direction of current:

\[ \text{Current} \]

9. [1] T F LEDs are only suitable for low-intensity applications such as indicator lights and small light bulbs.

10. [1] T F The light emitted from a LED, similar to laser light, is monochromatic.

11. [1] T F The light emitted from a LED, similar to laser light, is spectrally coherent.

12. [1] T F The light emitted from a LED, similar to laser light, is spatially coherent.

13. [1] What characteristic of the semiconductor in an LED determines its color?

14. [1] What is the optical phenomenon through which LEDs emit light?

15. [1] OLEDs are a relatively new technology with possible applications in thin, high-efficiency, low-cost displays. How do OLEDs differ from regular LEDs?

The electroluminescent material is an organic semiconductor.


- Photo diode
- OR
- Noise diode
- Hardware random number generator

17. [3] Assuming Shockley diode properties, qualitatively sketch a current-voltage characteristic curve for an LED:

- (i) Passes through origin, only in quadrants I and III
- (i) steep increase in current for positive V
- (i) very flat behavior for negative V
18. [2] Given a standard LED with a long leg and a short leg, which is the cathode, and which is the anode? Which way does current flow?

- Cathode is short leg, anode is long leg
- Current flows anode → cathode


a. [1] For what discovery was this Nobel Prize awarded?

b. [2] What is a possible application of this discovery?

- Make white LEDs
- By combining blue and yellow light

20. This question concerns various types of semiconductor materials used in producing different colors of LEDs.

a. For each question, give an example of a semiconductor material that can be used to produce an LED of the given color.

   i. [1] Red
   - Gallium arsenide
   - Aluminum gallium arsenide
   - Gallium arsenide phosphide
   - Aluminum gallium phosphide
   - Gallium nitride

   ii. [1] Green
   - Gallium phosphide
   - Aluminum gallium phosphide
   - Indium gallium phosphide

   iii. [1] Blue
   - Zinc selenide
   - Indium gallium arsenide
   - Sapphire
   - Gallium nitride

b. What color can the given semiconductor material produce in electroluminescence?

   i. [1] Gallium arsenide
   - Infrared

   ii. [1] Diamond
   - Ultraviolet

   iii. [1] Aluminum gallium phosphide
   - Green

   iv. [1] Aluminum gallium nitride
   - Ultraviolet
21. Consider the following circuit diagram

a. [2] Write an equation relating $V$, the voltage measured by the voltmeter, $V_1$, the voltage supplied by the battery, $R_1$, the resistance of the resistor, and $R_2$, the resistance of the thermistor. Assume the battery has negligible internal resistance.

$$\frac{V}{V_1} = \frac{R_2}{R_1 + R_2}$$

or equivalent

b. [4] What is the value of $V_1$?

c. [4] What is the value of $R_1$?

d. [2] What will $V$ be if $R_2$ is 500 $\Omega$? 

\[ V = \frac{500}{100 + 500} \Rightarrow V = 0.83 \text{ V} \]
22. The Steinhart-Hart equation for resistance of a semiconductor is given by

\[
\frac{1}{T} = A + B \ln R + C(\ln R)^3
\]

a. [5] Let \( x = \frac{1}{2c} \left( A - \frac{1}{T} \right) \) and \( y = \sqrt{\left( \frac{B}{3c} \right)^3 + x^2} \). Find \( R \) in terms of \( x \) and \( y \).

\[
R = \sqrt[3]{y - x - 3y + x}
\]

b. Given the following data table:

<table>
<thead>
<tr>
<th>Resistance (kΩ)</th>
<th>Temperature (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>6.5</td>
<td>35</td>
</tr>
</tbody>
</table>

i. [5] Solve for the Steinhart-Hart coefficients \( A \), \( B \), and \( C \).

\[
\begin{bmatrix}
1 & 10.1206 & 10584.7 \\
1 & 9.2103 & 791.317 \\
1 & 8.7196 & 676.734
\end{bmatrix}
\begin{bmatrix}
A \\
B \\
C
\end{bmatrix}
= 
\begin{bmatrix}
0.2 \\
0.041 \\
0.0286
\end{bmatrix}
\]

ii. [5] What is the temperature if the measured resistance is 2.5 kΩ?

\[
25 = 0.001431 \times 2.5 + 185, C = 2.781 \times 10^{-7}. \text{ All units in } K^{-1}
\]

iii. [5] What will the measured resistance be at a temperature of 70 ºC?

\[
\begin{bmatrix}
1.36143 \\
0.99626 \\
0.86722
\end{bmatrix}
\begin{bmatrix}
A \\
B \\
C
\end{bmatrix}
= 
\begin{bmatrix}
0.2 \\
0.041 \\
0.0286
\end{bmatrix}
\]

\[
2.5 = 0.001431 \times 2.5 + 185, C = 2.781 \times 10^{-7}. \text{ All units in } K^{-1}
\]

\[
R = 1.635 \text{ kΩ}
\]
§4: Device Components

23. Refer to the following diagram of a breadboard:

a. [2] How many distinct metal strips are in this breadboard?

b. [4] Suppose you had a battery, two wires attached to the positive and negative terminals of the battery respectively, and an LED. Indicate on the breadboard how you would light the LED, including polarities of all circuit elements, if applicable.

24. Refer to the following image of a multimeter:

a. [1] What is the most appropriate setting of the dial for measuring a voltage drop of 11 V?

b. [2] How should the voltmeter be connected to the circuit element in question?
c. [1] What is the most appropriate setting of the dial for measuring a current of 2746 μA? 25m

d. [2] How should the ammeter be connected to the circuit element in question? In series

25. Consider the following circuit diagram:

a. You note that the ammeter reading is very low. Thinking that your voltage isn’t high enough to drive the LED, you decide to increase the voltage supplied by your power source (perhaps by adding a few batteries). The ammeter reading persists to be low, until you increase the voltage more and the current suddenly increases and appreciable current flows around your circuit.

i. [1] Will the LED light in this configuration? No

ii. [1] Assume that now, the LED is flipped around and the voltage is reduced back to a more reasonable level. Will the LED light? No, it's broken

b. [1] You note that during this debacle, your resistor has heated up considerably. Assuming this particular resistor displays PTC characteristics, how does its resistance change? Increases