Detector Building
Answer Key
Captains Tryouts 2019 - 2020
(Montgomery)

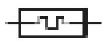
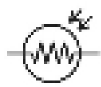
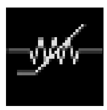
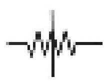
Names: ____

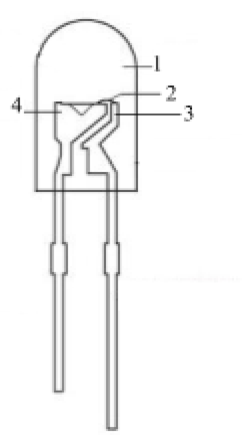
School: ____

Team #: ____

Score: ____/80

Multiple Choice Questions

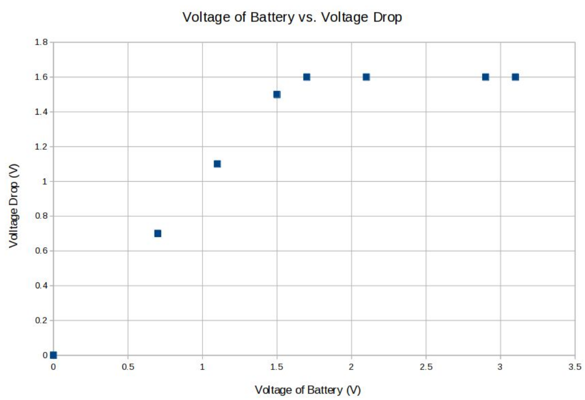
1. Which of the following is the circuit symbol for a thermistor? (__/1)
    a. 
    b. 
    c. 
    d. 
2. In which of these applications are NTC thermistors common? (__/1)
    a. Resettable fuses
    b. Overheating protection in motors
    c. Inrush current limiters
    d. Multiway switching
3. Match the LED components with their number on the diagram. (__/4)
    a. Lens: **1**
    b. Post: **3**
    c. Anvil: **4**
    d. Wire bond: **2**



4. Which of the following answers does the shorter lead of an LED correspond to? Choose two. (__/2)
    a. Positive terminal
    b. Negative terminal
    c. Cathode
    d. Anode
5. Which of these elements is least successful as a semiconducting material for an LED? (__/1)
    a. Gallium arsenide
    b. Zinc selenide
    c. Silicon
    d. Diamond
6. Which of the following elements serve as a dopant that creates holes in a semiconductor? (__/1)
    a. Aluminum
    b. Arsenic
    c. Germanium
    d. Antimony
7. In a standard resistor, when temperature increases what happens to the resistivity? (__/1)
    a. Resistivity decreases
    b. Resistivity stays the same
    c. Resistivity increases
8. Which of the following graphs would be the most conducive to finding the relationship between two quantitative variables? (__/1)
    a. Bar chart
    b. Scatterplot
    c. Dotplot
    d. Boxplot

Score:__/12

9. Which correlation coefficient would indicate a strong negative association? (__/1)
    a. r = 0.9
    b. r = 0.1
    c. r = -0.4
    d. r = -0.8
10. A battery is connected in series with a fixed resistor followed by a mystery component. The voltage of the battery is varied and the voltage drop across the mystery component is measured. A scattergram of the data values is given below. What would the mystery component most likely be? (__/1)



    a. Diode
    b. Resistor
    c. Battery
    d. Relay
11. A variable voltage (such as the one generated by a thermistor and a resistor arranged in a voltage divider) is best read in by a microcontroller through what sort of input? (__/1)
    a. Serial
    b. Digital
    c. Parallel
    d. Analog
12. Which of the following does not classify as a microcontroller? (__/1)
    a. Arudino
    b. TI Innovator
    c. Raspberry Pi
    d. 555 Timer IC
13. At 20℃, which of these materials have the highest temperature coefficient of resistivity? (__/1)
    a. Copper
    b. Tungsten
    c. Iron
    d. Lead

Free Response Questions

14. What does "LED" stand for? (__/1)

    Light emitting diode

15. Name three benefits that LEDs have over incandescent bulbs. (__/3)

    1. **Higher energy efficiency**
    2. **Longer lifespan and resilient**
    3. **Don't take time to warm-up**
    4. **Unaffected by low temperatures**
    5. **Physically smaller**
    6. **Better color rendering index**
    7. **Emits light directionally**

16. Complete the following statement? (__/2)

LEDs are **p-n** junctions that emit light free when electrons in the **n**-type semiconductor jump across the **depletion** layer, recombining with the holes in the **p**-type semiconductor, releasing energy in the form of photons.

17. Explain what "doping" is in relation to semiconductors. (__/2)

    Doping is the process of intentionally introducing impurities into a semiconductor (such as silicon) to change its properties. More specifically, doping is used to create an excess of electrons, such as by adding phosphorus, arsenic, or antimony to silicon, or to create a lack of electrons (holes), such as by adding boron or aluminum to silicon.

18. Explain the reason behind different colored LEDs. (__/2)

    The band gap of a p-n junction is the difference in energy of the conduction band and the valence band. LEDs are p-n junctions created from direct band gap semiconductors, meaning when electrons combine energy is not turned into lattice vibrations. Thus, the energy of the band gap corresponds only to the energy of light emitted in the form of photons. By varying the material of the semiconductor, with different band gaps, LEDs can vary the energy of the emitted photons and thus the wavelength and color of the light.

Score: __/10

19. The material used to construct a certain LED has a band gap of $2.29 * 10^{-19}$ J. Complete the following.
    a. Calculate the wavelength of light that the LED emits. (__/3)

    Because emitted photons have the same amount of energy as the band gap, by Planck's Lw can assert that $E = 2.29 * 10^{-19}$ J = hc/λ where h = Planck's constant = $6.63 * 10^{-34}$ m^2kg/s, c = speed of light = 3.00 * 10^8 m/s, and λ = wavelength.

    Solving, we get **$\lambda = 8.69 * 10^{-7}$m = 869nm**

    b. Name the type of light the LED emits. (__/1)

    A wavelength of 869nm corresponds to **infrared light**.

20. Explain the difference between NTC thermistors and PTC thermistors. (__/4)

NTC (Negative Temperature Coefficient) thermistors have resistance that decreases with increasing temperature while PTC (Positive Temperature Coefficient) resistors increases in resistance with increasing temperature

21. A thermistor has a resistance of 350Ω at 300K. Find the resistance of the resistor at 320K using a first-order approximation with a temperature coefficient of resistance of -5 Ω/K. (__/4)

Using a first order approximation, we know that $\Delta R = k\Delta T$, where k = thermal temperature coefficient of restiance = -5 Ω/K.

Plugging in values, we get (R_f - 350Ω) = -5 Ω/K * (320K - 300K)
R_f = -5 Ω/K * 20K + 350Ω = **250Ω**

22. An NTC thermistor has a resistance of 1200Ω at 40℃. Find the resistance of the resistor at -20℃ using a third order approximation with a β parameter of 200K. (__/4)

We know from the β parameter equation that $1/T = 1/T_0 + (1/\beta)\ln(R/R_0)$.

First we must convert the temperatures to Kelvin. 40℃ = 313K; -20℃ = 253K.

Thus, 1/(253K) = 1/(313K) + (1/200K)ln(R/(1200Ω))
Computing, we find 0.152 = ln(R/(1200)); $e^{0.152}$ = R/1200; 1.16 = R/1200; **R = 1397Ω**

23. Explain why resistance in a typical conductor varies with temperature, using arguments about what occurs on the molecular level. (__/3).

As temperature increases, thermal vibrations in the material increase. These thermal vibrations can be expressed as microscopic particles known as phonons. As electrons move through the resistor, they collide with the randomly moving phonons. The increase of temperature and thus phonons makes collisions more likely, obstructing electron flow and thus increasing resistance.

24. As the temperature of a conductor increases, thermal expansion may occur. Explain what impact thermal expansion has on the resistance of the conductor and if the phenomenon is significant towards the calculation of it's resistance. (__/3)

Resistance is given by ρL/A, where ρ is the resistivity, L is the length, and A is the area. When thermal expansion occurs, the area will increase, more so than the length, causing resistance to decrease. Thus, thermal expansion reduces the resistance as temperature increases. However, this phenomenon does not offset the gain in resistance from other factors (see 23), as the temperature coefficient of resistivity is typically far higher than the temperature coefficient of thermal linear expansion, making thermal expansion a fairly insignificant phenomenon in relation to the final resistance.

25. Does the resistance of silicon increase, decrease or stay the same as temperature increases? Explain why this is true. (__/3)

Increase **Decrease** Stays the same

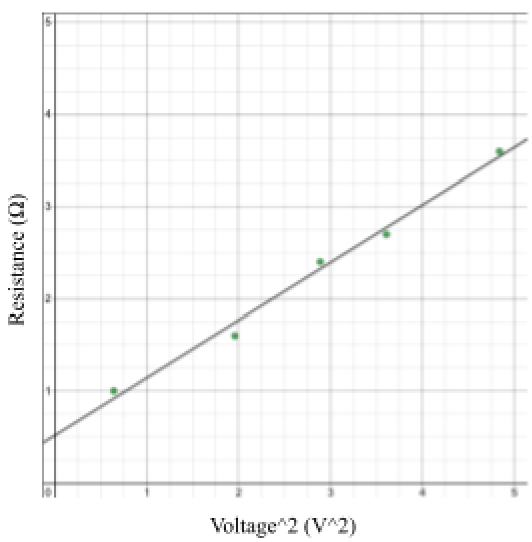
Score: __/13

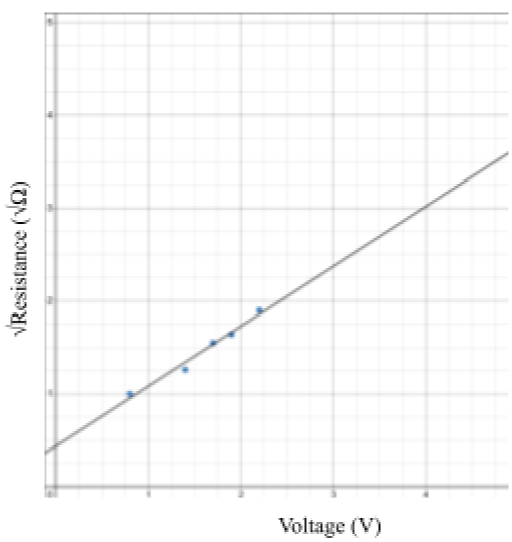
Silicon typically has no free electrons, due to having exactly four valence electrons. As temperature increases, so does the energy and thus the probability of a hole being generated from agitated electrons increases. These agitated electrons are now able to move around the lattice. Thus, increasing temperature increases free moving electrons, decreasing resistance.

26. A certain non-ohmic device increases in resistance as voltage increases and all other factors are held constant. Solve the following tasks using data regarding the device.
    a. Linearize the data below and use the blank data columns to show the linearized data. None, one, or both data columns may be needed. (__/2)

Voltage (V)	Resistance (Ω)	Voltage^2 (V^2)	√Resistance (√Ω)
0.80	1.00	0.64	1.00
1.40	1.60	1.96	1.26
1.70	2.40	2.89	1.55
1.90	2.70	3.61	1.64
2.20	3.60	4.84	1.90

    b. Graph the data and draw a regression line. (__/3)





Grade for properly labeled axis, correctly plotted data, and reasonable regression line ONLY ONE GRAPH IS NEEDED, USING THE PREVIOUS QUESTION'S DATA TABLE. REVERSING THE AXIS IS ALSO ACCEPTABLE.

Score: __/5

c. Approximate the slope of the regression line. (__/2)

For a part b graph of Voltage^2 on the x-axis and Resistance on the y-axis: R = 0.632V^2+0.516; slope = **0.632 Ω/V^2**; 10% tolerance -> range of **[0.567, 0.695]**

For a part b graph of Resistance on the x-axis and Voltage^2 on the y-axis: V^2 = 1.582V^2-0.787; slope = **1.582 V^2/Ω**; 10% tolerance -> range of **[1.424, 1.740]**

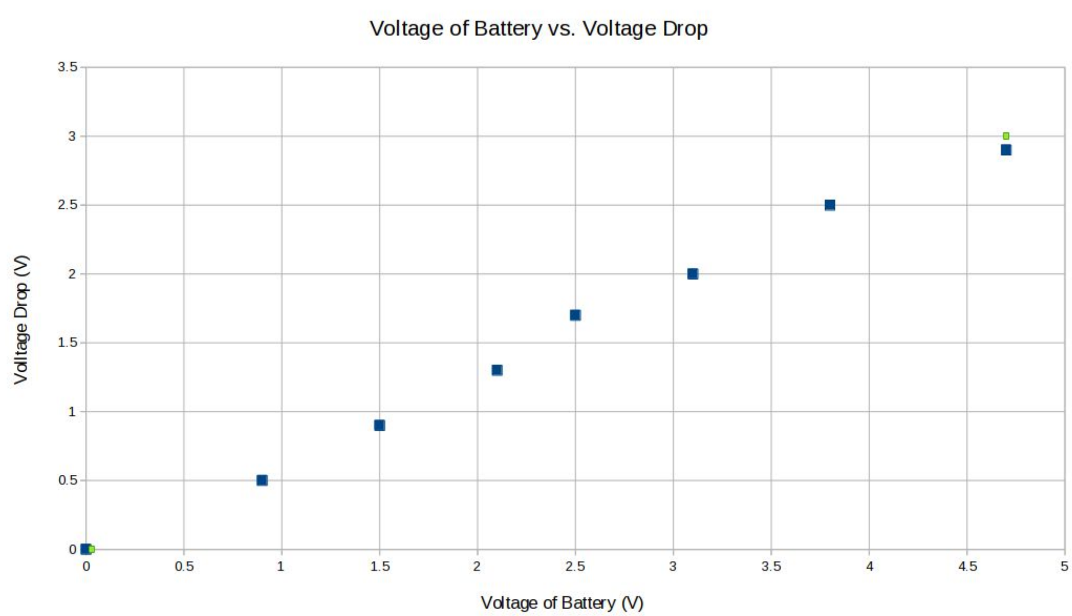
For a part b graph of Voltage on the x-axis and √Resistance on the y-axis: √R = 0.645V+0.438; slope = **0.645 √Ω/V**; 10% tolerance -> range of **[0.581, 0.710]**

For a part b graph of √Resistance on the x-axis and Voltage on the y-axis: V = 1.515√R-0.627 slope = **1.515 V/√Ω**; 10% tolerance -> range of **[1.3635, 1.667]**

d. Solve for the resistance of the device when voltage is equal to 3V. (__/2)

Plugging into one of the previous equations, R = 0.632V^2+0.516, R = 0.632*3^2+0.516 = **6.204Ω**; 10% tolerance -> range of **[5.584, 6.824]**

27. A battery is connected in series with a fixed resistor followed by a mystery component. The voltage of the battery is varied and the voltage drop across the mystery component is measured. A scattergram of the data is given below. Accomplish the following tasks.



a. Write a linear equation modeling the relationship shown in the scattergram. (__/2)

Let V_D be the voltage drop and V_B be the voltage of the battery.

The ideal regression line is $\mathbf{V_D = 0.643V_B - 0.019}$; 10% tolerance for slope -> range of **[0.579, 0.707]**; y-intercept should be close to **0**

b. Predict the value of the voltage drop when the battery voltage is 6.1V. (__/2)

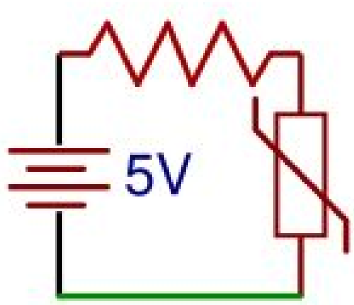
Plugging into the previous equation, $V_D = 0.643*6.1 - 0.019 = 3.90V$; 10% tolerance -> range of **[3.51, 4.29]**

c. Circle what the mystery component most likely may be. (__/1)

Diode **Resistor** Battery Relay

28. A thermistor is connected in series with a 1000Ω resistor. The thermistor is attached to the positive terminal of a 9V battery, while the 1000Ω resistor is attached to the negative terminal of the same battery. At the ambient temperature of the environment, the thermistor has a resistance of 1200Ω. Complete the following tasks.

a. Draw a circuit diagram of the described situation. (__/2)



Score: __/7

b. Find the voltage of the circuit between the thermistor and the 1000Ω resistor. (__/2)

Using the voltage divider equation, Voltage = 9V*(1200Ω)/(1200Ω+1000Ω) = **4.91V**

If the thermistor and resistor are reversed in the previous question, the answer may have been incorrectly found to be Voltage = 9V*(1000Ω)/(1200Ω+1000Ω) = 4.09V

29. The purpose of calibrating a scientific instrument is to measure and adjust the precision and accuracy of the device. Define those two terms.

a. Precision (__/1)

Precision refers to the consistency of your data or the degree to which repeated measurements of the same unchanged condition yield the same result.

b. Accuracy (__/1)

Accuracy refers to how close the measured data is to the true value.