January 18th, 2020

Detector Building Division C Exam

Duke Science Olympiad

Time: 50 minutes **Resources:** one 2” binder, two stand-alone calculators of any type

- Write your team number on every page.
- You may rip up the test, so long as all pages are returned in order.
- This test contains 6 questions, each with multiple parts.

Team Name: ______________ **KEY** ______________ **Team Number:** __________

Competitor Names: ______________________________

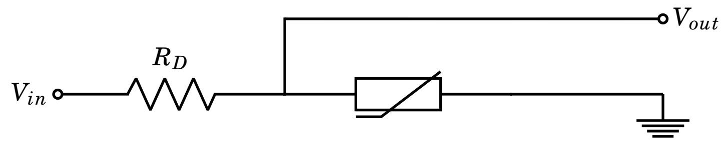
As always, do your best and forget the rest. Good luck!

For official use only:

Questions:	1	2	3	4	5	6	Total
Points:	10	10	10	10	10	10	60
Score:	**10**	**10**	**10**	**10**	**10**	**10**	**60**

This page was once a tree, and once it was blank. Now it is neither. You can make it less blank if you like. Turning it back into a tree is more effort, but also more worthwhile.

1. Consider the following circuit containing a NTC thermistor at 20°C.



The thermistor is governed by the following equation

$$\frac{1}{T} = 2.75 \cdot 10^{-3} + 4.56 \cdot 10^{-4} \ln(R),$$

where R is in Ω and T is in Kelvin.

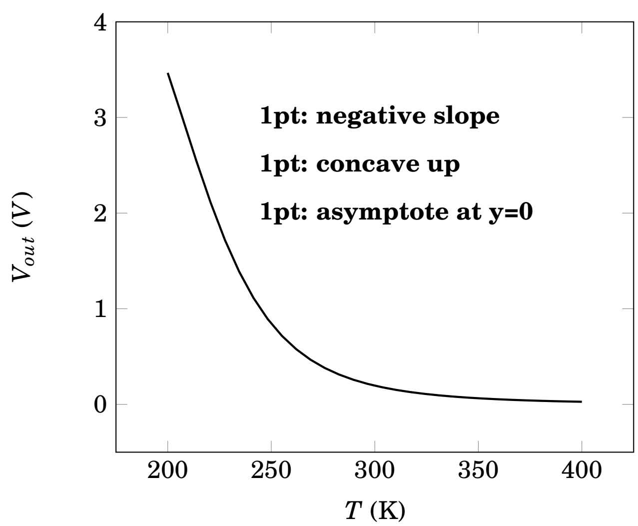
(a) (2 points) In this situation, what is the resistance of the thermistor, in Ω?

4.26

(b) (2 points) If the temperature increases, would you expect the voltage across R_D increase, decrease, or stay the same?

Increase

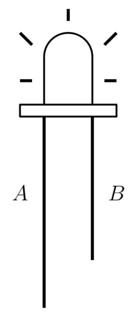
(c) (3 points) In the graph provided, qualitatively show the voltage V_{out} with respect to the temperature of the thermistor if $V_{in} = 5.0\,\text{V}$ and $R_D = 100\,\Omega$.



(d) (3 points) A relay is an electromechanical switch that triggers when the voltage across its two input terminals exceeds a voltage V_R. This relay is attached to the V_{out} terminal. Assuming the values from above, if $V_R = 3.0\,\text{V}$, find the temperature at which the relay will trigger, in Kelvin. Show work.

- **(1 pt) Finds the resistance of the thermistor using voltage divider equation,** $R_T = 150\,\Omega$**.**
- **(2 pt) Finds temperature of** $200\,\text{K}$**.**

2. Consider the following diagram of an LED.



(a) (1 point) What does "LED" stand for?

Light emitting diode

(b) (1 point) Which of the legs, A or B, represents the anode?

A

(c) (1 point) In which direction do electrons flow: from the anode to the cathode or from the cathode to the anode?

Cathode to anode.

(d) (1 point) Which leg contains the n side of the p-n junction?

B

(e) (1 point) What category of material is present in a p-n junction?

Semiconductor

(f) (1 point) What's the main advantage of LED's over standard incandescent lights?

More efficient.

(g) (1 point) What happens to an LED if too much current is run through it?

It explodes.

(h) (1 point) What's the maximum number of 2.4 V LED's you can run off of a 5.0 V power supply?

2

(i) (2 points) Consider the table consisting of the LED material and its corresponding wavelength?

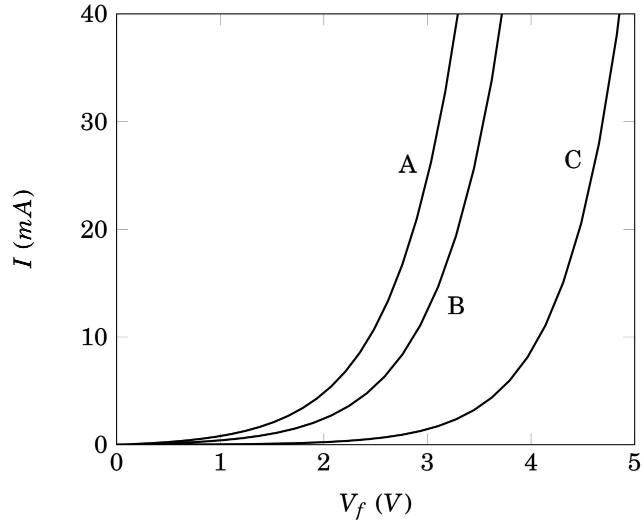
Material	GaAs	GaAsP	GaAsP	GaAsP:N	AlGaP	SiC
Wavelength (nm)	850-940	630-660	605-620	585-595	550-570	430-505

Which LED(s) would you pick if you wanted to create the color white on an computer screen?

GaAsP, AlGaP, SiC

Points earned: **10** / 10

3. Consider the following current vs. voltage curves of three LED's.



(a) (3 points) Which is the most likely to be a red LED? Why?

- **(1 pt) LED A**
- **(2 pt) Band gap for red LED is smaller, so less voltage needed to run it**
- **If student says something similar to "Red needs less energy to run," give (1 pt).**

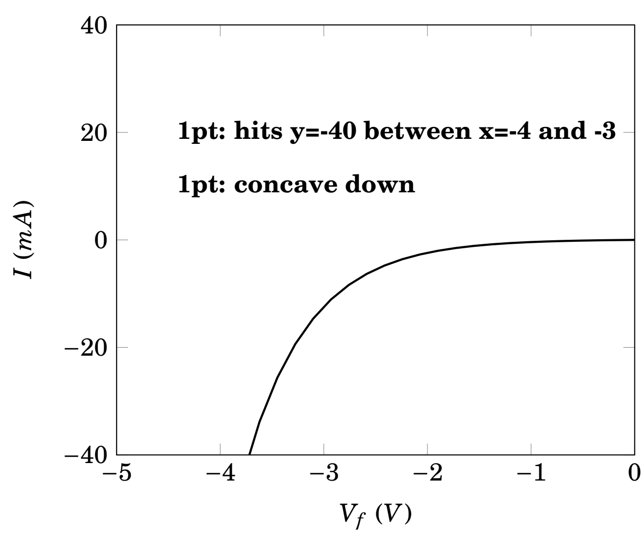
(b) (3 points) These three LED's are put in parallel and a voltage of 3.0V is applied across them. Which one(s), if any, would you expect to light up? Why?

- **(2 pt) A and B**
- **(1 pt) 3V is before the diode knee of C, but above that of A and B**

(c) (2 points) What equations are being plotted here? In other words, what equation describes the $I-V$ curve of an LED?

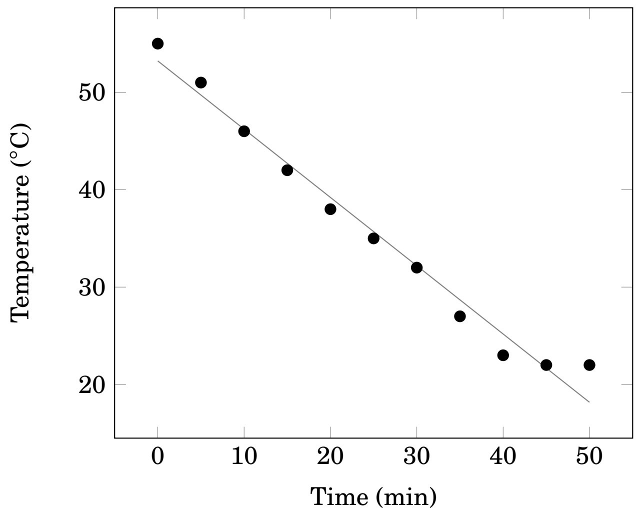
- **(2 pt) Shockley diode equation.**

(d) (2 points) Suppose the direction of the current was reversed in diode B. **Qualitatively** draw the resulting current vs. voltage curve on the graph provided.



Points earned: **10** / 10

4. You left your temperature sensor in an aluminum beaker of water by accident, and it collects the following data over time.



The linear regression has equation

$$\text{Temperature} = -0.702 \cdot (\text{Time} - 25) + 35.7.$$

(a) (1 point) Estimate room temperature.

21-23 °C

(b) (2 points) At what time did the water reach room temperature?

40 min

(c) (2 points) If the points after the time from (b) are removed, will the **magnitude** of the slope of the linear regression increase or decrease?

Increase

(d) (2 points) In your original data, it turns out you placed the temperature sensor near the edge of the beaker. You repeat your trials, but this time you place the sensor in the center of the beaker. Is the **magnitude** of the slope of the resulting linear regression greater or less than that of your original trials? Justify briefly.

- **(1pt) Less than**
- **(1pt) Exterior is aluminum → conducts heat well → temperature in periphery drops faster than the center → temperature drops more slowly in the center (answer just needs the basic idea)**

(e) (3 points) Knowing that each data point is spaced five minutes apart, what is the significance of the value 35.7? How do you know?

- **(1pt) Mean temperature throughout**
- **(2pt) Evenly spaced → 25 is mean of x-values → $(\overline{x}, \overline{y})$ necessarily on regression line → 35.7 is mean of y-values**

Points earned: **10** / 10

5. You and Alex are using a fictitious microcontroller, an Anton-ino, whose code is written in the similarly fictitious language Snake. However, the two of you don't seem to be getting reasonable values in the outputs. You're using a standard voltage divider circuit with a $R_1 = 15000$ Ohm resistor. Lines marked with *(Correct)* can be assumed to have no errors.

```
1  int ThermistorPin = 0 #(Correct)
2  float Vo # Defines output voltage
3  float R1 = 12000 # Defines resistance of fixed resistor
4  float R_2, T # Defines R2 and T
5
6  # Defines Steinhart-Hart coefficients
7  int c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07
8
9  if (device.setup() = GOOD): # Checks whether everything is okay (Correct)
10         device.start() # (Correct)
11
12 void loop(): # Function that loops every 500 ms to read output voltage (Correct)
13         Vo = analogRead(ThermistorPin) # Reads the output voltage (Correct)
14         R2 = R1 * (256.0 / (Vo - 1.0)) # Calculates the resistance of the second resistor
15
16         # Calculates temperature (Correct)
17         T = (1.0 / (c1 + c2*log(R2) + c3*log(R2)*log(R2)*log(R2)))
18
19         T2 = T - 273.15
20         T = (T2 * 9.0)/ 5.0 + 32.0
21
22         device.delay(500,seconds)  #Sets a delay until the function runs again
23         print(T) # Prints T (Correct)
```

(a) (3 points) What are the three main errors in lines 2-7?

1. **(1 pt) Line 3** `R1` **should be defined as 15000, not 12000**
2. **(1 pt) Line 4** `R2` **defined instead as** `R_2`. `R2` **is used later.**
3. **(1 pt) Line 7 should be** `float` **not** `int`.

(b) (2 points) According to this code, how many bits is the Analog to Digital Converter (ADC)?

8 bit

(c) (2 points) What are the final units of T? This isn't what you want. What line(s) should you remove to correct for this?

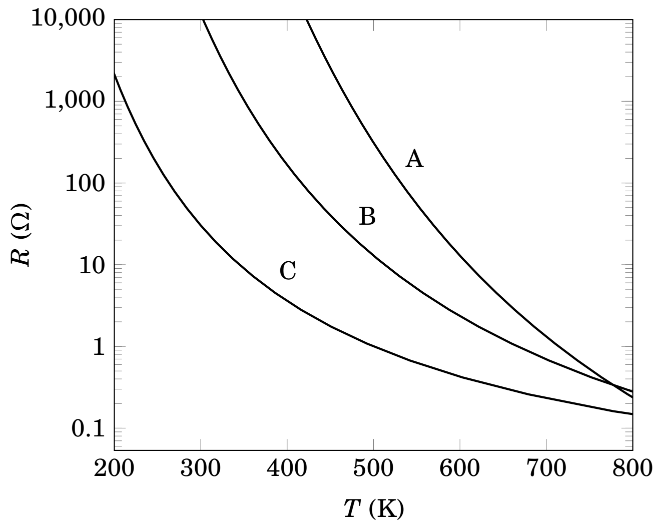
- **(1 pt)** T **is in Fahrenheit.**
- **(1 pt) Remove line 20.**
- **Saying both 19 and 20 is acceptable too.**

(d) (3 points) What are the three main errors in lines 12-23? What would you change to correct for these?

- **(0.5 pt) Incorrect parentheses when solving for R2. (0.5 pt) Should be** `R2 = R1 * (256.0 / Vo - 1.0)`.
- **(0.5 pt)** `T2` **is never initialized/defined. (0.5 pt) Should include a** `float T2` **somewhere.**
- **(0.5 pt) Wrong device delay. (0.5 pt) Should be** `device.delay(0.500,seconds)`

Points earned: **10** / 10

6. Consider three thermistors: A, B, and C, whose curves are plotted below.



(a) (3 points) Which of the three thermistors would you pick to measure resistances between 200°C and 300°C with a digital ohmmeter? Why? Assume the ohmmeter measures to 3 significant figures.

- **(1 pt) Thermistor A**
- **(2 pt) Since the multimeter has a set level of significance, you want the thermistor which has the greatest change in resistance for a given change in temperature in order to overcome the uncertainty. Thermistor A has the steepest slope.**

(b) (3 points) Now suppose instead of using a multimeter, you're using a voltage divider circuit similar to Question 1, and you're using a microcontroller with a 4-bit ADC (Analog to Digital Converter). Which of the three thermistors would you pick to measure temperatures between 200°C and 300°C? Why?

- **(1 pt) Thermistor C**
- **(2 pt) The ADC splits the voltage range into linear chunks, in this case 15 of them. So the output value of the ADC V_{ADC} is $V_{ADC} = 15R_T/(R_T + R_D)$ where R_D is the voltage of the voltage divider resistor. For large R_T, though, such as thermistor A, the change is V_{ADC} is very small, so you have less accurate readings.**
- **The difference between this and (a) is that here is that we're using a voltage divider to measure the voltage, instead of doing so directly.**

(c) (2 points) Estimate the constant term of the Steinhart-Hart equation of thermistor B using the graph without a calculator or solving a system. Briefly explain.

- **(1 pt) Any answer between** $1.4 \cdot 10^{-3} \pm 1 \cdot 10^{-4}$
- **(1 pt) Want the logarithmic terms to be 0, so pick** $(700, 1)$. **So, the answer is approximately** $1/700$ **by Steinhart-Hart.**

(d) (2 points) Suppose you left a constant voltage running through thermistor C in a room with ambient temperature 30°C. What will happen to the resistance of the thermistor as times goes on, if anything? Explain.

- **(1 pt) Decrease.**
- **(1 pt) The thermistor heats up over time (it is a resistor after all), so the temperature increases, decreasing the resistance.**

Points earned: **10** / 10