DETECTOR BUILDING C

PRINCETON UNIVERSITY SCIENCE OLYMPIAD INVITATIONAL TOURNAMENT 2020

TEAM ______________________ C - _______ *example: Science Olympiad High School*		SCORE _______ / 75
NAME(S) ______________ ______________		

INSTRUCTIONS

1	You have the duration of this event block (up to 50 minutes) to complete as many questions as you can on this exam.
2	Please limit responses to 1-3 sentences per question. Full sentences are not required. You will not be penalized for writing a lot, but doing so may take time away from answering other questions.
3	Explain and show your work for calculations unless otherwise noted. Units are required.
4	All tiebreaker questions are included in the test score. There are no penalties for incorrect answers.
5	Please write your team number on each page.
6	You will need two specification sheets to complete parts of this test. They are titled "NTE3019 / Light Emitting Diode (LED) / Red Diffused, 5mm" and "NTC Thermistors, Radial Leaded, Standard Precision."
7	If you brought a laptop for programming your device, only your programming application (IDE) may be open while you are working on this written test.
8	Your total score on this test will be multiplied by (30 / 75) to convert it to a score out of 30 points (as required by rule 6.b.iv.).

QUESTIONS

1	**What does the initialism LED stand for? What does each word mean about LEDs?** LED stands for "light-emitting diode." "Light-emitting" means that LEDs produce light, and "diode" means within operational limits it only conducts appreciable current in one direction. *1 point – "light-emitting diode"* *1 point – emits light* *1 point – function as diode*	____ / 3
2	**List an example application for each of the following LED outputs: visible, ultraviolet, and infrared.** Visible: electronic displays, lighting, etc. Ultraviolet: ultraviolet curing, digital print, disinfection, counterfeit detection, etc. Infrared: remote-control applications, security, etc. Any answers not listed will be verified. *1 point – visible application* *1 point – ultraviolet application* *1 point – infrared application*	____ / 3
3	**Your partner has snipped the leads/wires on all of your through hole infrared LEDs so that they can all be the same length. How can you still identify the anode and cathode without making any electrical connections?** Can use the asymmetry of an LED (cathode on side with anvil and flat spot, anode on side with post). *2 points – correct answer (maximum 1.5 points if asymmetry is described backwards)*	____ / 2

4	**<u>Tiebreaker 3</u>: A 9 V battery is connected in series with a resistor and an NTE3019 LED in forward bias. Using the provided specification sheet for NTE's NTE3019 5 mm red diffused LED, calculate the range of resistor values in Ohms that would allow the LED to operate within its specified range.** Closed loop equation is $V_{battery} - V_{LED} - V_R = 0$ which can be rewritten as $R = \frac{V_{battery} - V_{LED}}{I_R}$ and recommended forward voltages range from 1.65 to 2.0 V. Therefore, recommended resistances are between 350 and 367.5 Ω. *2 points – using an equation that is correct* *1 point – identifying forward voltage from specification sheet* *1 point – correct lower resistance (350 Ω)* *1 point – correct upper resistance (367.5 Ω)* *1 point – correct units (Ω) on final answers*	____ / 6
5	**Which of the following statements comparing LEDs is correct? Write the letter corresponding to an answer choice here: ______.** **a. LEDs, like LASERs, emit monochromatic temporally coherent light due to high Q-resonance of both systems; however, by design light from most LEDs is not spatially coherent.** **b. LEDs have a relatively longer useful lives, and unlike incandescent lighting their failure is usually gradual.** **c. Both LEDs and photodiodes are forward-bias components that involve conversions between light and electrical energy (in different directions).** **d. LEDs emit more lumens per watt than incandescent lighting, but both radiate similar amounts of heat.** **e. Both a. and b.** **f. Both a. and c.** a. LEDs do not emit coherent light. b. This is the correct answer. c. Photodiodes are reverse biased. d. LEDs are thermally more efficient. *3 points – correct answer (b)*	____ / 3
6	**Which of the following statements about thermistors is correct? Write the letter corresponding to an answer choice here: ______.** **a. Increased resistance is expected when a hot soldering iron is held in close proximity to an NTC thermistor (in its operating temperature range).** **b. The R_25 value specifies the minimum resistance that can be measured on a PTC thermistor.** **c. Reversing an NTC thermistor used as an inrush current limiter will make it a PTC thermistor with the opposite function.** **d. While NTC thermistors decrease in resistance with increasing temperature, PTC thermistors always increase in resistance with increasing temperature.** **e. Both NTC and PTC thermistors are popular choices for managing current draw by electrical devices.** **f. None of the above are correct.** a. Expect the opposite result: decreased resistance with increased temperature. b. R_25 specifies resistance at 25 degrees Celsius. c. Not true. d. PTC resistance-temperature profiles are not always increasing; see transition temperature. e. This is the correct answer: NTC are popular for inrush current, and PTC are popular for overcurrent. *3 points – correct answer (e)*	____ / 3
7	**<u>Tiebreaker 4</u>: Resistance temperature detectors (RTDs) use a coiled conductive metal wire (commonly made of platinum) to sense temperature changes. Describe what occurs at a molecular level to produce this temperature-resistance relationship.** Temperature increase in the metal wire at the molecular level causes increased movement of electrons which collide more frequently with nearby atoms, molecules, etc. This impedes the organized motion of electrons in the direction (opposite) of current flow, thereby increasing resistance. *2 points – connecting temperature increase to increased movement* *2 points – connecting collisions to increased resistance*	____ / 4

8	**What is occurring at a molecular level for temperature detection by both an NTC and PTC semiconductor-based thermistor?** NTC: Increasing temperature increases the number of charge carriers that can be promoted to the conduction band. With more charge carriers (electrons, holes) available, resistance decreases. PTC: Many are made from doped ceramic that increases in resistance above a certain critical/transition temperature (otherwise acts as NTC). Thermally sensitive silicon resistors have an almost linear temperature-resistance relationship (like RTDs). *1 point – connecting temperature increase to charge carriers (NTC)* *1 point – connecting availability of charge carriers to resistance (NTC)* *1 point – one explanation for PTC transistors*	____ / 3
9	**How do resistance temperature detectors (RTDs) and semiconductor-based thermistors compare in sensitivity to temperature changes?** Thermistors are more responsive to small temperature changes due to their nonlinear temperature-resistance relationship, whereas RTDs have an approximately linear temperature-resistance relationship. *1 point – comparing responsiveness to temperature changes* *1 point – thermistors have nonlinear relationship* *1 point – RTDs have approximately linear relationship*	____ / 3
10	**An alternative Steinhart-Hart equation with the form T = B / (ln(R) – A) – C is computationally faster for a computer at a slight expense to accuracy. Why might such a tradeoff be acceptable?** A measurement that updates frequently will be more responsive to temperature changes than one that updates infrequently (even if more accurately), especially when measuring rapidly changing temperatures. *3 points – reasonable answer discussing tradeoff between responsiveness and accuracy*	____ / 3
11	**Describe a method for reducing noise in the signal obtained from your temperature measurement device.** Accept reasonable answers including: applying a filter (such as frequency-based or moving average). *1 point – any reasonable answer*	____ / 1
12	**Explain how the low thermal mass of common thermistors affects both responsiveness and accuracy.** Low thermal mass means faster response to temperature changes, but prone to self-heating errors (i.e. temperature changes in the device due to inefficiency that contribute error to temperature readings). *1 point – low thermal mass and responsiveness to temperature changes* *1 point – self-heating effect*	____ / 2
13	**What specification determines whether a 5 mm LED with anode connected to the positive terminal and the cathode to the negative terminal of a 24 V output power supply will breakdown?** (Maximum) reverse voltage. *1 point – correct answer*	____ / 1
14	**Provide two reasons for adhering to maximum ratings for a component, even if it continues to operate outside of its specified range.** Acceptable answers include: electrical/safety hazard, loss of accuracy, (early) device failure, overheating, underperformance, etc. *1 point – providing one reasonable reason* *1 point – providing one reasonable reason*	____ / 2
15	**True or false: A correlation coefficient with magnitude close to 1 indicates that the form of the attempted fit properly explains the underlying relationship of the data in question. Write the letter corresponding to your answer choice here: ______.** **a. True.** **b. False.** Correct answer is false. Could have many issues involving error, good fit but wrong relationship, aliasing, etc. *1 point – correct answer*	____ / 1

<u>Questions 16-24</u>: The remainder of the questions reference the specification sheet for Vishay's NTCLE100E3 NTC thermistors.

16 **<u>Tiebreaker 1</u>: Referencing the B parameter on the provided datasheet, estimate the resistance at 85°C for a thermistor with color code red-red-black.** ____ / 6

Use the B parameter equation: $R_T = R_R \cdot e^{B\left(\frac{1}{T}-\frac{1}{T_R}\right)}$.

$R_{85} = R_{25} \cdot e^{B_{25/85}\left(\frac{1}{T_{85}}-\frac{1}{T_{25}}\right)} = (22\ \Omega) \cdot e^{(3136\ K)\left(\frac{1}{85+273.15\ K}-\frac{1}{25+273.15\ K}\right)} = 3.78\ \Omega \approx 3.8\ \Omega$

1 point – using correct equation
2 points – using correct values from specification sheet
2 points – correct answer
1 point – correct units (Ω) on final answer

17 **Should NTCLE100E3 thermistors be used to measure the temperature of dry ice (which is around -79°C)? Why or why not?** ____ / 2

No, because the temperature of dry ice is below the specified operating temperature range.

1 point – no
1 point – providing an explanation

18 **The specification sheet mentions "zero power." What does this mean and how does it affect operation?** ____ / 2

Zero power refers to when the thermistor is not electrically loaded, i.e. unloaded, zero current. When a thermistor is electrically loaded, self-heating effects may not be negligible.

1 point – describing zero power dissipation
1 point – describing effect on thermistor operation

Your partner has gathered the following temperature and resistance data using an NTCLE100E3 thermistor but has since forgotten which thermistor they used.

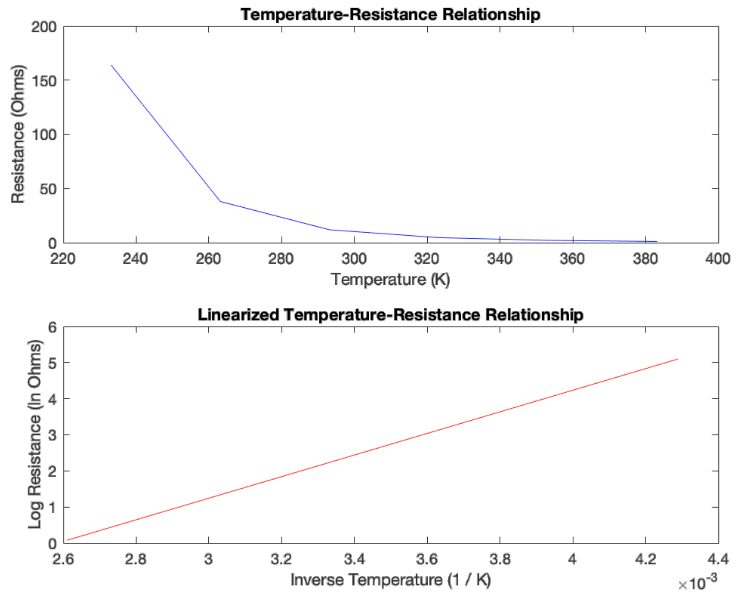
Temperature (°C)	**Resistance (Ω)**
-40.	163.8
-10.	38.0
20.	11.9
50.	4.6
80.	2.1
110.	1.1

19 **<u>Tiebreaker 2</u>: First, linearize the temperature/resistance data, and fill in the table below, making sure to include appropriate units. Very briefly describe what operations you performed to linearize data (to allow for partial credit if your numbers are off).** ____ / 6

1 / Temperature (1 / K)	**Ln Resistance (ln Ω)**
0.00430	5.098
0.00380	3.64
0.00340	2.47
0.00310	1.5
0.00280	0.74
0.00260	0.095

4 points – correctly linearizing all data points (each number is a third of a point)
1 point – labeling temperature column and including correct units
1 point – labeling resistance column and including correct units

20	**Plot the linearized data in the space below.**	___ / 3



Only the bottom plot is required. The code included below outputs these plots in MATLAB.

1 point – reasonable attempt at plotting data (even if incorrect)
½ point – reasonable range on axes
½ point – labeling horizontal axis with units
½ point – labeling vertical axis with units
½ point – including a title

```
clear all; close all; clc;

T = (-40:30:125) + 273.15; % temperature range in K
B = 2990; % units K
R0 = 10; % units Ohms
T0 = 25 + 273.15; % units K
R = R0 * exp(B * (1 ./ T - 1 ./ T0)); % estimated resistances in Ohms

figure (1);
subplot(2, 1, 1); plot(T, R, '-b');
title('Temperature-Resistance Relationship');
xlabel('Temperature (K)'); ylabel('Resistance (Ohms)');
subplot(2, 1, 2); plot(1 ./ T, log(R), '-r');
title('Linearized Temperature-Resistance Relationship');
xlabel('Inverse Temperature (1 / K)'); ylabel('Log Resistance (ln Ohms)');

P = polyfit(1 ./ T, log(R), 1)
```

21	**Determine an equation that describes your linearized data. Include units and define any variables you use.**	___ / 5

ln(Resistance) = [2990 K * (1 / Temperature) – 7] ln(Ω)

1 point – writing a correct linearization equation: slope
1 point – writing a correct linearization equation: intercept
2 points – variables/parameters in equation match linearization operations (e.g. inverse temperature)
1 point – correct units used in equation/variable definitions

22	**Comment on the slope of your linearized fit and the temperature coefficient for this thermistor.**	___ / 2

Linearized data has a positive slope. Thermistor is still negative temperature coefficient (NTC).

2 points – a reasonable observation, preferably the one stated above

23	**Mention one reason for linearizing your experimental data.** Linearization can be used to check relationships (e.g. data that isn't logarithmic shouldn't linearize with a log function). Linear relationships are easier to conceptualize (there is a degree of proportionality). Linear relationships are easier to visualize (e.g. easy to tell if something is a line, but hard to tell if something is exponential or quadratic in a small region). *3 points – a good reason for linearization*	____ / 3
24	**Using the linearized equation for this temperature-resistance relationship, determine the B parameter for this thermistor. What color code does this value correspond to? If more than one color code matches, list all that match.** Examining the B parameter equation $R_T = R_R \cdot e^{B\left(\frac{1}{T}-\frac{1}{T_R}\right)}$ reveals that the slope of the linearized equation is the B parameter. This B parameter is 2990 K and corresponds to the color brown-black-black. Note that depending on the format of the linearized equation, the solution may be not as direct. *2 points – correctly identifying B parameter from linearized equation* *1 point – identifying color code corresponding to B parameter*	____ / 3
25	**Did you return all borrowed materials and dispose of waste? Is your working space dry and clear for the next team?** Yes. *3 points – the team performed all actions requested in the question*	____ / 3