C - Detector Building C 2020-2021 - BEARSO - 10-24-2020

Welcome to Detector Building! The test below is designed to be an extended version of the test you would normally receive in a Detector Building event, with some lab questions in lieu of having a real lab portion. Some questions in this exam involve mathematics and diagrams. For these questions, you must write your work and answer on a piece of paper and scan and upload it at the end, preferably as a pdf. Make the subject of your email "BEARSO Detector Building C Work Submission". **If you do not have this as your subject I will not be able to see your work. Clearly label the number of the question to which your work pertains and be as explicit in showing your work as possible.** To allow enough time for uploads but to enforce academic integrity, you will have 50 minutes for the test and then 10 minutes to upload your work. Emails received after the 10 minute period (the end of the hour) will not be accepted. I know this is the first test of an online platform, so if you guys have trouble with submissions, you can also upload the rest of your answer in an email to me -- just make sure you label the subject appropriately. The test has a total of 128 points divided into sections whose point total is stated in the test. I hope you "bear" with me as we figure out this online format! Good luck and have fun!

Part 1: Operational knowledge of thermosensors

Point total: 15

1. (3.00 pts)
Compared to Resistance Temperature Detectors (RTDs), thermocouples generally have a ____________ (wider, narrower) temperature range, ___________ (higher, lower) accuracy, and a ____________ (higher, lower) cost.

wider | lower | lower

2. (1.00 pts)
The condition where a thermosensor's readout not only depends on its current sensor environment but also its previous sensor environment is called ___________. This effect becomes apparent during temperature cycling.

hysteresis

3. (2.00 pts) The condition in the above question primarily occurs because:

- ○ A) The metal used to measure temperature expands while heating and contracts while cooling; the resulting change in cross sectional area changes the heating coefficient.
- ● B) The metal used to measure temperature expands while heating and contracts while cooling; the different times for expansion and contraction mean that the temperature sensed will lag the true temperature.
- ○ C) The metal used to measure temperature is often impure. Dopant elements in the metal change its reading differently while heating up or cooling down.
- ○ D) The metal used to measure temperature is often impure. The other metal contaminants also contribute to the sensor reading, resulting in a weighted average of all the metals.

In questions 4-9 below, choose the thermosensor that is best described in the question.

4. (1.00 pts) This thermistor is very expensive and thus is only used in high temperature applications (up to ~1900K). It is very stable but has low sensitivity.

- A) Type T (Copper Constantan)
- B) Type N (Nicrosil-Nisil)
- C) Type K (Chromel-Alumel)
- D) Pt/Rh-Pt
- E) W/Re-W/Re
- F) Type J (Iron Constantan)

5. (1.00 pts)
This thermocouple has a very wide temperature range, being able to measure things down to 0K and up to 1600K with relatively high stability. This thermocouple is also stable in many different environments, but has slightly lower sensitivity.

- A) Type T (Copper-Constantan)
- B) Type N (Nicrosil-Nisil)
- C) Type K (Chromel-Alumel)
- D) Pt/Rh-Pt
- E) W/Re-W/Re
- F) Type J (Iron-Constantan)

6. (1.00 pts)
This thermocouple has a small temperature range (~50K - 600K) but has slightly higher precision compared to other thermocouples. It exhibits very smooth characteristics since both conductors are non-magnetic and thus don't have a Curie point.

- A) Type T (Copper-Constantan)
- B) Type N (Nicrosil-Nisil)
- C) Type K (Chromel-Alumel)
- D) Pt/Rh-Pt
- E) W/Re-W/Re
- F) Type J (Iron-Constantan)

7. (1.00 pts) This thermocouple has a somewhat restrictive usable range (~200K - 1000K) but is extremely sensitive.

- A) Type T (Copper-Constantan)
- B) Type N (Nicrosil-Nisil)
- C) Type K (Chromel-Alumel)
- D) Pt/Rh-Pt
- E) W/Re-W/Re
- F) Type J (Iron-Constantan)

8. (1.00 pts)
This thermocouple is a standard general purpose thermocouple. It has moderate precision and a respectable temperature range (~50K - 1600K). It is very inexpensive and works best in oxidizing atmospheres; reducing atmospheres will cause it to break down.

- A) Type T (Copper-Constantan)
- B) Type N (Nicrosil-Nisil)
- C) Type K (Chromel-Alumel)
- D) Pt/Rh-Pt

- ○ E) W/Re-W/Re
- ○ F) Type J (Iron-Constantan)

9. (1.00 pts) This thermocouple is used at extremely high temperatures (up to 3000K) and operates best in inert atmospheres.

- ○ A) Type T (Copper-Constantan)
- ○ B) Type N (Nicrosil-Nisil)
- ○ C) Type K (Chromel-Alumel)
- ○ D) Pt/Rh-Pt
- ◉ E) W/Re-W/Re
- ○ F) Type J (Iron Constantan)

10. (3.00 pts) Which of the following is true when comparing RTDs and thermistors?

(Mark **ALL** correct answers)

- [x] A) Both rely on a resistance to temperature relation.
- [x] B) RTDs are typically made from pure metals while thermistors are made from polymer or ceramic materials like metal oxides.
- [x] C) RTDs have a larger viable temperature range while thermistors are more precise in their temperature range.
- [x] D) Both can be either PTC or NTC
- [ ] E) Both rely on the Seebeck effect to produce a voltage from a temperature reading.
- [x] F) Both are fairly fragile and must be housed in protective equipment and treated with care.

Part 2: Knowledge of LEDs and Diodes

Point total: 33

Questions 11-12 refer to the history of LEDs.

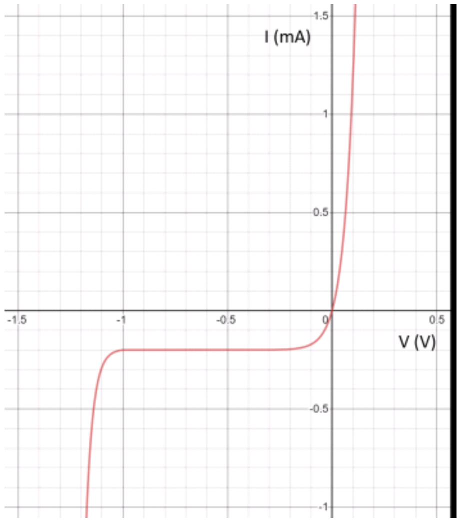
11. (3.00 pts)
The first LEDs produced were generally ______ (red, green, blue, white), and it was not until decades later that _______ (red, green, blue, white) LEDs were produced at high brightness and quantity. Shortly after, the ______ (red, green, blue, white) LED was produced, although the same color could be produced from combining other LED colors.

red | blue | white

12. (4.00 pts) In the question above, why were the early LEDs so much easier to produce than the ones invented decades later?

Expected Answer: (2 points - 1 for mentioning difficulty of material, 1 for explaining the bandgap problem) For the blue LED compared to the red LED, it was much harder to find a semiconductor material with the needed band gap energy to make blue light. Even those semiconductors with the necessary bandgap, like Gallium Nitride, are difficult to make. (2 points - 1 for mentioning difficulty of material, 1 for explaining that the precise difficulty is to get multiple colors in the right proportions to trick our eyes.) For the white LED, we needed to find a way to emit multiple colors. A material was needed to emit multiple colors in the right proportions to trick our eyes into seeing white light.

The diagram below gives the I-V curve of a diode. Use this diagram for questions 13-16.



13. (3.00 pts)
Using bracket set notation, indicate the voltage ranges that pertain to the breakdown region, reverse bias region, and forward bias region in that order. Ex., [-1, 1] means voltages -1 V to 1 V. For negative infinity, use (-inf and for positive infinity, use inf). Be sure to format your answer with a space after the comma. Units will be implicit in answer as volts.

(-inf, -1]

[-1, 0]

[0, inf)

14. (3.00 pts)
Using the graph above, find values for the: saturation current (nearest 0.1 mA), ideality factor (or quality factor, nearest integer), and breakdown voltage (nearest 0.1 V). Include units in your answer.

0.2 mA

2

-1 V

15. (5.00 pts) Assume this diode is ideal in the reverse and forward bias regions. Calculate the current that would flow at 0.1 V power supply if the diode was heated to 350K.

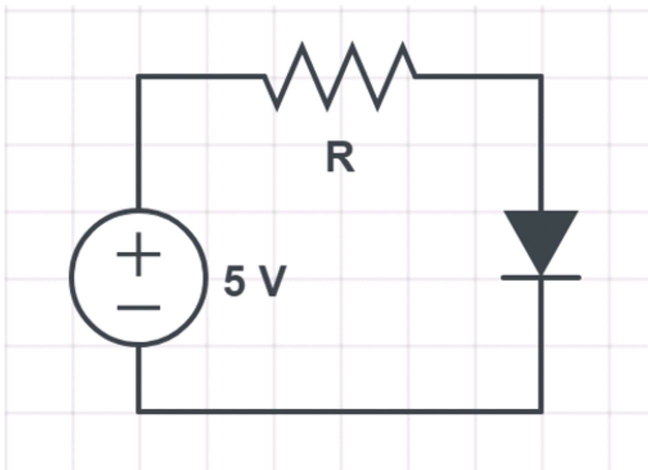
0.85 mA

16. (5.00 pts)
What would be the new saturation current if the cross sectional area and the intrinsic carrier concentration of the diode was tripled, but the donor and accepter concentrations were halved? (nearest 0.1 mA)

10.8 mA

Questions 17-18 refer to the circuit in question 17.

17. (5.00 pts)
You are given the circuit below and are told that the LED is 100% efficient, but it is unknown what color of light the LED emits. The resistor given is a variable resistor. What range of values of R should you try that could produce a red light in the LED? Red light can be 630 nm to 700 nm in wavelength. Specify the lower bound (to the nearest Ohm) in the first box and the upper bound in the second box. You may assume the LED operates at a current of 10mA.



303 | 323

18. (5.00 pts)
Using the same circuit above, now suppose R is 100 Ω. Attach another resistor R2 in parallel with the LED and give the values of R2 that make the LED shine red light. You can again assume the LED is 100% efficient and operates at 10mA. Fill the first blank with the lower bound for R2 and the second blank with the upper bound for R2, to the nearest Ohm.

80 | 97

Part 3: Working with empirical data

Point total: 19

19. (3.00 pts) Which of the following are smoothing functions to reduce noise in a time series measurement?

(Mark **ALL** correct answers)

- [ ] A) Band Pass Filter
- [x] B) Local Regression
- [ ] C) Method of Fourier Coefficients
- [x] D) Spline smoothing
- [ ] E) Taylor's Approximation
- [ ] F) Variation of Parameters

20. (4.00 pts)
The data below show thermocouple recordings for a sample of water being heated. The data is smoothed using an exponential moving average. Use the data to determine the weights and fill in the two missing values. Put the missing recorded temperature in the first blank and the smoothed temperature in the second blank. Then solve for the time constant of the smoothing function and put it in the third blank. You may leave your answer to two decimal places.

Time (s)	T (K)	Smoothed T (K)
0	290	290.00
0.1	289	289.00
0.2	288	288.40
0.3	291	289.96
0.4	292	291.18
0.5	290	290.47
0.6		291.99
0.7	291	291.40
0.8	292	291.76
0.9	294	293.10
1	290	291.24
1.1	293	292.30
1.2	293	292.72
1.3	294	293.49
1.4	294	293.79
1.5	293	

293.00

293.32

0.11

21. (5.00 pts)
You are planning to measure a voltage using a 5.0 V microcontroller with an ADC. Derive an expression for the number of bits, n, you'll need on your ADC if you want a voltage precision of p.

Expected Answer: n = log_2(5/p)

22. (3.00 pts)
An LED in a circuit emits light at a wavelength of 650nm. You attach a 6.0 V microcontroller with an 8-bit ADC to a voltmeter to measure the voltage drop across the LED. What should your ADC display on your computer, in binary? Leave your answer as a 13 bit binary number preceded by "0b". For example, the binary representation of 5 would be 0b00000101.

0b01010010

23. (4.00 pts)
Your LED circuit from the previous question is not perfect and the wavelength of light coming from it is wavering a little bit. However, the digital readout from your 8-bit ADC is not wavering at all. What are the smallest and highest possible wavelengths your LED could be wavering between, to the nearest 0.1 nm?

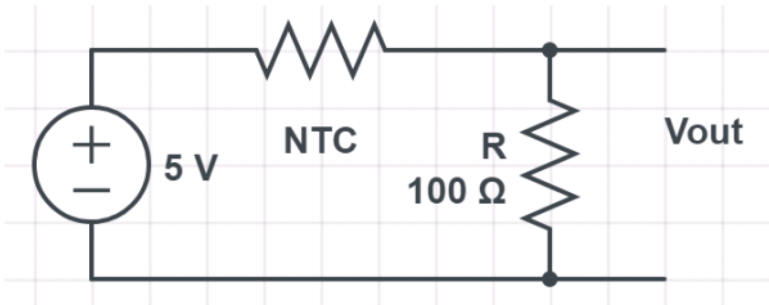
638.7

654.4

Part 4: Thermistors in Circuits

Point Total: 21

24. (5.00 pts) In the circuit below, the NTC has a B of 3000K. Vout is measured to be 0.26 V at 300K. Give Vout as function of temperature (in Kelvin).



Expected Answer: Vout =500/[100+0.08277exp(3000/T)]

Questions 25-28 below are grouped together and refer to thermistor calculations.

25. (3.00 pts)
A thermistor given to you is known to have resistance 2 kΩ at 298 K and a resistance temperature coefficient of -11.26 Ω/K. Using this information, determine the resistance at 373 K. Leave your answer as a number in kΩ to two decimal places.

1.16

26. (3.00 pts)
The same thermistor as question 25 is given to you again. It is still 2 kΩ at 298 K, but now you are given its B parameter is 500. Using this information, calculate its resistance at 100 K. Leave your answer in kΩ to two decimal places.

1.43

27. (5.00 pts) Your answers to the previous two questions should differ. Is one answer more accurate than the other? If so, state which is more accurate and why.

Expected Answer: Using resistance temperature coefficient is a first order approximation (1 point), only valid in temperature ranges around the measured temperature and resistance (1 point). The B equation is a higher order approximation (1 point) and can be accurate up to a 200 deg C range (1 point). Therefore the answer to question 23 is more accurate (1 point).

28. (5.00 pts)
In question 25, you used a constant k resistance temperature coefficient to determine resistance at a higher temperature, and saw that the answer differed from that in question 11. Now determine a k as a function of temperature, k(T), such that using k(T) in problem 25 would produce the same answer as problem 26. Also show that at room temperature (298 K) your expression for k evaluates to -11.26 Ω/K.

Expected Answer: k(T) = -(186775*exp(500/T))/T k(298) = -11.26 Ω/K

Part 5: Semiconductors

Point total: 18

29. (8.00 pts)
Draw a band structure diagram for an indirect band gap semiconductor. Indicate the Fermi level, conduction band, valence band, energy gap, and momentum transfer. Put energy on the vertical axis and k points on the horizontal axis.

Expected Answer: https://drive.google.com/file/d/1NDrpoo1fBEWgZEzNofZ8sVcu6ZYUcDEl/view?usp=sharing Drawing indicates an indirect (1 point) band gap (1 point) with parabola shaped bands (or approximate parabola shapes near the band gap) (1 point) Fermi level indicated correctly (1 point) Conduction band indicated correctly (1 point) Valence band indicated correctly (1 point) Energy gap indicated correctly (1 point) Momentum transfer indicated correctly (1 point)

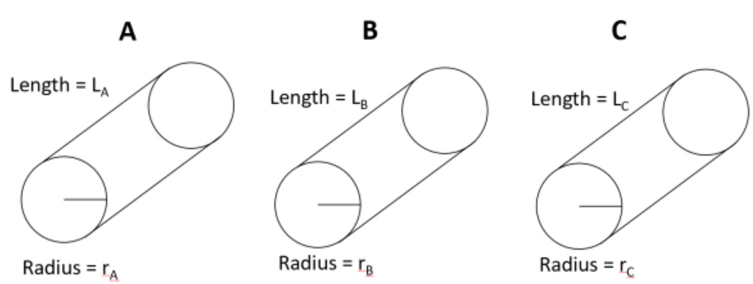
30. (10.00 pts)
Draw an energy level diagram for a p-n junction. Use energy on the vertical axis and position on the horizontal axis. Label which side is p type and which side is n type. Label the Fermi level, conduction band, and valence band. Indicate the directions of generation and recombination current for p and n type carriers, as well as the condition that puts this junction in equilibrium.

Expected Answer: https://drive.google.com/file/d/1FmATIIDq26hwFEiOuIUCAAkrsjGoFqSi/view?usp=sharing Band shapes are correct (p bands are higher) (1 point) p type is labeled correctly (1 point) n type is labeled correctly (1 point) Fermi level is labeled correctly (1 point) Conduction band (1 point) and valence band (1 point) are labeled correctly Generation currents for p (1 point) and n (1 point) and recombination currents for p (1 point) and n (1 point) are labeled correctly Condition for equilibrium is correctly stated (1 point)

Part 6: Lab Questions

Point total: 22

31. (10.00 pts)
One day in the lab you mix up three wires of unknown material without labels (shown below). You want to set up an experiment to determine what material each wire is. The materials, shown as wires A, B, and C, are all currently sitting at room temperature (298K). You have access to one reliable hot water source at 373K, one reliable room temperature water source (298K), one reliable ice bath water source (273K), a voltmeter, thermal conducting wire, graduated cylinders, insulating cups of varying sizes, resistors ranging from 10 ohms to 100 kΩ, a timer, and a thermometer. Design an experimental setup to determine the materials. Explicitly state the materials you will use, the design of the setup, the measurements that will be made, any material lookup tables you need (e.g. table for tensile strength of certain materials), as well as any equations necessary to determine the materials. You may assume the wires are well insulated. Indicate possible sources of error in your experiment for full credit.



Expected Answer: (1 point) materials needed (1 point) design setup and (1 point) reasoning for design setup (1 point) stating the measurements needed and (2 points) stating how these measurements will be used to determine the materials (1 point) stating the lookup tables/values needed (1 point) stating the equations needed to go from measurements to physical interpretation and (1 point) if these equations are correct. (1 point) Sources of error Example (limited due to word limit): Setup hot water bath, cold water sample to measure temperature change through wire, place close together to reduce error. Measuring temperature change from a cold water sample using a hot water bath. Use these measurements to determine rate of heat transfer, and use the dimensions of the wires to determine thermal conductivities. Look up thermal conductivities in a table. Error from time delay in temperature change and the conducting wires.

32. (12.00 pts)
After running your experiment above, you determine the materials to be iron, a copper-nickel alloy (constantan), and copper. Now you go to run the experiment you came in to do – measuring the temperature of a solution you've been brewing. But as you walk over to the setup, you drop your only thermometer! Now that you know which blocks are which material, describe how you can use any (or all) of these blocks to measure the temperature of the sample. You may use the materials stated in the previous question. Explicitly state the materials you will use, the design of the setup, the measurements that will be made, any lookup tables needed, as well as any equations necessary.

Expected Answer: (1 point) materials needed (1 point) design setup and (1 point) reasoning for design setup (1 point) for recognizing these are thermocouple materials (1 point) for correct choice of which blocks to use (if thermocouple setup, use Fe-constantan or Cu-constantan) (1 point) stating the measurements needed and (2 points) stating how these measurements will be used to determine temperature (1 point) stating the lookup tables/values needed (1 point) stating the equations needed to go from measurements to physical interpretation and (1 point) if these equations are correct. (1 point) Sources of error Example: A thermocouple can be made with either Fe-constantan or Cu-constantan. Dip one end of the wires into the unknown temperature sol. and the other into a water bath (ref T). Measure the voltage across the reference ends and look up the Seebeck coefficients of the materials. Determine T using V = int[Tref, Tsample](difference in seebeck coefficients). Error: impurities, time delay.

Congratulations, you have reached the end of the test! I hope you had fun!