Detector Building

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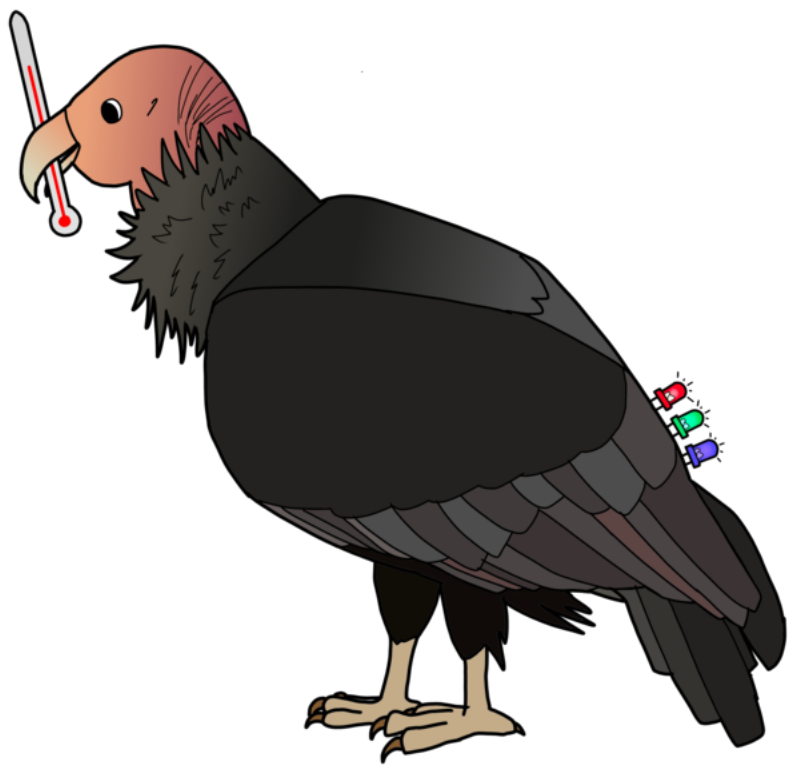
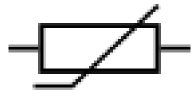


Directions:

- We don't really care about significant figures, just ensure that your answer is reasonable (has to be distinguishable)
- Show work on calculation questions to receive partial credit in the case that your final answer is incorrect. Work is not required but recommended. You do not need to show every minor step, but include the big ideas to demonstrate your understanding.

1. (2 points) What circuit element is this?



   A. Thermistor
   B. Resistor
   C. Linear Potentiometer
   D. Switch
   E. Thermocouple
   F. Rotary Potentiometer

2. (2 points) What circuit element is this?

   A. Thermistor
   B. Resistor
   C. Transistor
   D. Switch
   E. Thermocouple
   F. None of the Above

3. (2 points) Why are alloys such as constantan and manganin preferred for creating resistors?
   A. They have a high temperature coefficient of resistance
   B. They have a low temperature coefficient of resistance
   C. They have lower resistances to minimize energy loss
   D. They are more ductile and adequate for use in resistors
   E. Two of the above answers are correct
   F. None of the Above

4. (3 points) In which direction will the current flow in an LED?
   - ○ From the anode to the cathode
   - ○ From the cathode to the anode
   - ○ From the shorter leg to the longer leg
   - ○ From the longer leg to the shorter leg
   - ○ From positive to negative
   - ○ From negative to positive

5. (2 points) Where is the flat spot on an LED located?
   A. On the side that should be connected to ground
   B. On the side that should be connected to the positive voltage source
   C. In the direction that light is emitted
   D. Opposite the direction that light is emitted
   E. Two of the above answers are correct

F. None of the Above

6. (2 points) What color of light corresponds to wavelengths between 500 and 565 nm?

   A. Red

   B. Yellow

   C. Green

   D. Blue

   E. Ultraviolet

   F. White

7. (2 points) Which of the following semiconductors might you see in a blue LED?

   A. Aluminium gallium arsenide

   B. Gallium(III) phosphide

   C. Gallium arsenide phosphide

   D. Indium gallium nitride

   E. Boron nitride

   F. Aluminium gallium indium phosphide

8. (6 points) What is the relationship between the forward voltage of an LED V and the wavelength of light λ that it emits. Express your answer in terms of fundamental constants.

9. (2 points) When are epoxy bead thermistors preferred over glass bead thermistors?

   A. Detecting temperatures in fluids

   B. In a reducing environment

   C. In an oxidizing environment

   D. Vacuums, used as a Pressure Gauge

   E. Low temperature Applications

   F. None of the Above

10. (3 points) A 10K Ohm thermistor at 25 °C has a beta value of $\beta = 3400$. If you detect a thermistor resistance of 7K Ohms, what is the environment temperature, in °C?

    A. 25.02

    B. 25.07

    C. 29.11

    D. 34.63

    E. 53.33

    F. Not enough information

11. (6 points) You want to model your thermistor using the Steinhart-Hart equation. You take 3 data points: 27020 Ohms at 9 °C, 9870 Ohms at 28 °C, 4650 Ohms at 43 °C. Find the Steinhart-Hart coefficients (A, B, C) for the thermistor.

12. (2 points) What metals can be found in the positive and negative wires of a type K thermocouple?

    A. Copper, Constantan

    B. Nicrosil, Nisil

    C. Chromel, Alumel

D. Chromel, Constantan

E. Copper, Chromel

F. Iron, Constantan

13. (3 points) For which of the following types of thermocouples will the characteristic function be influenced at the Curie Point?

◯ T

◯ J

◯ E

◯ K

◯ N

◯ Thermocouples are not influenced at the Curie Point

14. (3 points) Which of the following types of thermocouples is suitable for measuring temperature continuously in environments less than 0 °C?

◯ T

◯ J

◯ E

◯ K

◯ N

◯ None of the Above

15. (4 points) When using Type J thermocouples at very high temperatures, it is recommended to use large gauge wires. Why?

16. (2 points) What are the three main junction types of sheathed thermocouple probes?

A. Closed, Open, Guarded

B. Exposed, Grounded, Ungrounded

C. Grounded, Ungrounded, Guarded

D. Exposed, Unexposed, Guarded

E. Exposed, Closed, Grounded

F. None of the Above

17. (2 points) What most likely happens if the wires of a thermocouple begin to oxidize?

A. EMF output is increased, and temperature is overestimated

B. EMF output is increased, and temperature is underestimated

C. EMF output is decreased, and temperature is overestimated

D. EMF output is decreased, and temperature is underestimated

E. The thermocouple will short circuit, providing meaningless results

F. The thermocouple will be an open circuit, providing meaningless results

18. (6 points) Pure platinum has a temperature coefficient of resistance 0.003925 1/°C. Consider a pure platinum RTD with resistance 1K Ohms at 100°C. What is its resistance at 0°C?

19. (2 points) What is the most common way to achieve different coefficients of resistivity in a Platinum RTD?

A. It is impossible to achieve a different coefficient of resistivity

B. Superheating Platinum such that the thermophysical properties are shifted

C. Supercooling Platinum such that the lattice structure is altered

D. Platinum doping

E. None of the Above

20. (6 points) Suppose we have an arbitrary RTD with temperature coefficient of resistance 0.003825 1/°C and resistance 915 Ohms at 0 °C. We are modeling this RTD using the Callendar-Van Dusen equation, such that $A = 3.91 \cdot 10^{-3}$ °C^{-1} and $B = -5.78 \cdot 10^{-7}$ °C^{-2}. What is its resistance at 45 °C?

21. (6 points) Compare thermistors, thermocouples, and RTDs. List 2 advantages of each over the others, and differentiate between their applications.

22. (2 points) Given 2 identical resistors and an ideal voltage source, a current of 8 A is produced when the resistors are connected in parallel to the voltage source. What is the current produced when the resistors are in series?

A. 0.5 A

B. 1 A

C. 2 A

D. 4 A

E. 8 A

F. None of the Above

23. (3 points) Which of the following statements are true?

○ Lasers are not spatially coherent

○ LEDs appear to emit a pure color

○ LEDs are not spectrally coherent

○ LEDs do not contain p-n junctions

○ Lasers are highly monochromatic

○ The working principle behind LEDs is electroluminescence

24. (4 points) Pure semiconductors are called ______________ while doped semiconductors are called ______________.

25. (3 points) Select all of the following true statements.

○ Resistivity increases as a semiconductor's temperature is reduced.

○ Resistivity decreases as a semiconductor's temperature is reduced.

○ Resistivity increases as a metal's temperature is reduced.

○ Resistivity decreases as a metal's temperature is reduced.

○ Conductivity increases as a semiconductor's temperature is reduced.

○ Conductivity remains the same as a semiconductor's temperature is reduced.

26. (4 points) Explain the behavior for both metals and semiconductors for your answer to the previous question.

27. (3 points) What is the name of the device that can determine if a sample of semiconductor is n-type or p-type?

____

28. (2 points) Which group of the periodic table do most n-type dopants come from?

A. 13

B. 14

C. 15

D. 16

E. 17

F. 18

29. (2 points) Which element is the most commonly used p-type dopant?

A. Phosphorus

B. Aluminium

C. Gallium

D. Boron

E. Arsenic

F. Indium

30. (3 points) Elements from which two groups form binary compound semiconductors?

◯ III

◯ IV

◯ V

◯ VI

◯ VII

◯ VIII

31. (6 points) Why does the resistance of an insulator decrease as its temperature is increased? Your answer should mention the band gap.

32. (3 points) Name a natural phenomenon where the behavior in the previous question can be observed. ______________

33. (2 points) What occurs in a degenerate semiconductor?

A. It acts similarly to a metal

B. It acts similarly to an insulator

C. It acts similarly to an undoped semiconductor

D. It depends on whether the semiconductor is n-type or p-type

E. It forms a depletion region

F. It forms a potential difference

34. (2 points) What differentiates a semi-insulator from ordinary semiconductors?

A. It has a larger band gap

B. It has a smaller band gap

C. None of the Above

35. (3 points) What is the name of the positively charged quasiparticle caused by the lack of an electron? ______________

36. (3 points) What is the term for the event when the quasiparticle in the previous question meets an electron? ______________

37. (4 points) What two types of particles are emitted by the process described in the previous question? What types of energy do they represent?

38. (2 points) What is the majority carrier in a p-type semiconductor?

A. electrons

B. protons

C. positrons

D. electron holes

E. neutrons

F. antiprotons

39. (6 points) A sample of germanium has an intrinsic carrier concentration of $2 \cdot 10^{13}$ cm^{-3}. If doping the sample with arsenic results in a minority carrier concentration of $4 \cdot 10^{8}$ cm^{-3}, what is the concentration of the majority carrier?

40. (2 points) Keeping all else constant, by what factor will the free-electron concentration in a semiconductor change if the effective density of states at the valence band edge is doubled?

A. 0.25

B. 0.5

C. 1

D. 2

E. 4

F. 8

41. (2 points) What is the relationship between the energy of the Fermi level E_F, the energy of the conduction band E_c, and the energy of the valence band E_v in a semiconductor?

A. $E_F < E_c < E_v$

B. $E_F < E_v < E_c$

C. $E_c < E_F < E_v$

D. $E_c < E_v < E_F$

E. $E_v < E_F < E_c$

F. $E_v < E_c < E_F$

42. (2 points) What is the relationship between the energy of the Fermi level E_F, the energy of the conduction band E_c, and the energy of the valence band E_v in an insulator?

A. $E_F < E_c < E_v$

B. $E_F < E_v < E_c$

C. $E_c < E_F < E_v$

D. $E_c < E_v < E_F$

E. $E_v < E_F < E_c$

F. $E_v < E_c < E_F$

43. (3 points) What is the name of the region along a p-n junction where there is an absence of charge carriers?

____

44. (4 points) What happens to the region described in the previous problem when the junction is placed under forward bias? reverse bias?

45. (3 points) What is the name of the potential difference that forms across the region described in question 44?

____

46. (3 points) For a semiconductor not undergoing breakdown, which of the following statements are true?

○ Under forward bias, majority carriers travel macroscopic lengths

○ Under forward bias, minority carriers travel macroscopic lengths

○ Under reverse bias, majority carriers travel macroscopic lengths

○ Under reverse bias, minority carriers travel macroscopic lengths

47. (4 points) What is the type of breakdown that occurs in lightly-doped p-n junctions? ______________ heavily-doped? ______________

48. (3 points) Consider an ordinary diode under reverse bias. The voltage across is increased until it undergoes breakdown and is returned back to normal. Assuming the diode has not been permanently changed, which of the following statements are true.

    ◯ The current through the diode is the same as it was initially.

    ◯ The current through the diode is more than it was initially.

    ◯ The current through the diode is less than it was initially.

    ◯ The current through the diode is primarily through majority carriers.

    ◯ The current through the diode is primarily through minority carriers.

    ◯ The current through the diode is primarily through both majority and minority carriers.

49. (6 points) Why can a Zener diode be operated past its breakdown voltage?

50. (6 points) How can a Zener diode be used as a voltage regulator?

51. (2 points) Metrological traceability in calibration is often represented as a pyramid, where the tip of the pyramid is the true value, and uncertainty increases as you go down the pyramid. What lies at the base of the pyramid?

    A. International Calibration Laboratory

    B. National Calibration Laboratory

    C. Accredited Calibration Laboratory

    D. Plant's Process Instruments

    E. Plant's Working Standard

    F. Plant's Reference Standard

52. (6 points) Manufacturer labels on resistors can provide temperature coefficients of resistance in either 1/°C or 1/K. First, explain why this is not a problem. Second, provide a scenario where we need to use Kelvin instead of degrees Celsius, and why.

53. (2 points) Suppose we have a silicon diode with forward voltage 0.7V in series with a 10 Ohm resistor and a 9V emf source. Assuming that the current in the circuit is non-zero, what is the current in the circuit?

    A. 0.90 A

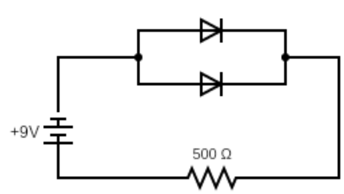
    B. 0.97 A

    C. 0.83 A

    D. 0.63 A

    E. None of the Above

54. (2 points) Consider the circuit below. One of the diodes is a germanium diode with forward voltage 0.3V, and the other diode is a silicon diode with forward voltage 0.7V. What is the current in the circuit?



    A. 16.0 mA

    B. 16.6 mA

C. 17.4 mA

D. 17.6 mA

E. None of the Above

55. (2 points) Which of the following resistor color codes corresponds to the highest resistance?

A. Brown, Black, Orange, Violet

B. Green, Blue, White, Brown, Gold

C. Violet, Red, Black, Black, Grey

D. Yellow, Brown, Red, Red

E. Orange, Green, Red, Red, Silver

F. Red, Orange, Brown, Black, Green

56. (2 points) Which of the following resistor color codes corresponds to the largest tolerance?

A. Brown, Black, Orange, Violet

B. Green, Blue, White, Brown, Gold

C. Violet, Red, Black, Black, Grey

D. Yellow, Brown, Red, Red

E. Orange, Green, Red, Red, Silver

F. Red, Orange, Brown, Black, Green

57. (2 points) Which of the following resistor color codes corresponds to the smallest absolute uncertainty?

A. Brown, Black, Orange, Violet

B. Green, Blue, White, Brown, Gold

C. Violet, Red, Black, Black, Grey

D. Yellow, Brown, Red, Red

E. Orange, Green, Red, Red, Silver

F. Red, Orange, Brown, Black, Green

58. (2 points) Which of the following is an accurate description of an overfitted model?

A. A model that very closely matches the data

B. A model that was modified to exactly reproduce the data

C. A model that was fit to too many input points

D. A model that performs better on unseen data than the training data

E. A model that is linear where a nonlinear model should have been used instead

F. A model with more parameters than can be justified

59. (6 points) When taking multiple samples, should population or sample standard deviation be used? Why?

60. (2 points) Which of the following is not a reason to use the Pearson correlation coefficient to measure the correlation between two variables?

A. It is symmetric in terms of the two variables.

B. It is invariant to changes in location for both variables.

C. It reflects all types of correlation, not just linear.

D. It can easily be converted into the coefficient of determination.

E. It is a normalized value and is invariant to scaling.

F. None of the Above

61. (2 points) If the number of samples of a measurement is increased by a factor of a hundred, by what factor does the standard error change?

A. 0.0001

B. 0.01

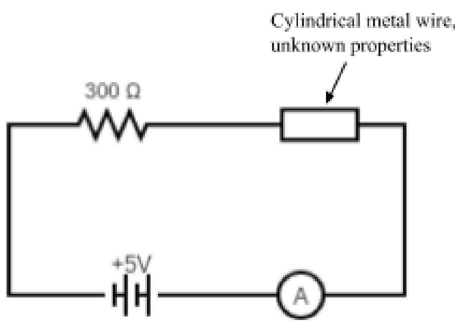
C. 0.1

D. 10

E. 100

F. 1000

62. (5 points) Given that 6 samples of a measurement have a mean of 5.68 and a standard deviation of 1.12, determine the confidence interval for the true value of the parameter. Use a confidence level of 95

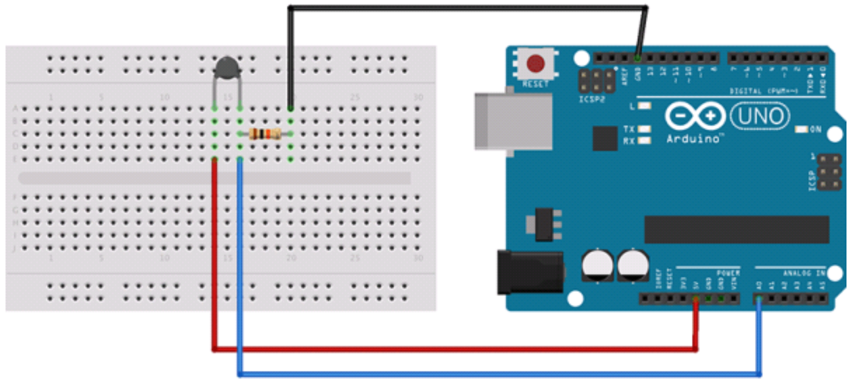


63. (4 points) Observe the setup above. If the ammeter reads 0.0125A, what is the resistance of the cylindrical metal wire?

64. (4 points) Suppose that the original cylindrical metal wire from part 1 is replaced with one with double the radius and double the length. What will the ammeter read with this new setup?

65. (6 points) Return to the setup with the original cylindrical metal wire from part 1. Suppose that the ambient temperature is 20 °C. Remove the cylindrical metal wire, heat it up until its temperature is 50 °C, and return the wire to the circuit. You observe that the ammeter now reads 0.0121A. What element is the wire made out of? You may refer to the table of temperature coefficients for various metals, provided below.

Material	Element/Alloy	"alpha" per degree Celsius
Nickel	Element	0.005866
Iron	Element	0.005671
Molybdenum	Element	0.004579
Tungsten	Element	0.004403
Aluminum	Element	0.004308
Copper	Element	0.004041
Silver	Element	0.003819
Platinum	Element	0.003729
Gold	Element	0.003715
Zinc	Element	0.003847
Steel*	Alloy	0.003
Nichrome	Alloy	0.00017
Nichrome V	Alloy	0.00013
Manganin	Alloy	+/- 0.000015
Constantan	Alloy	-0.000074



You and your partner have started working on your device, and you are curious about how accurate your measurements are, and if you can improve them. You are using an Arduino Uno with a 10 bit ADC. The resistor has a resistance of R with uncertainty δR. You're using the $5V$ reference voltage pin. Use the above diagram as a reference for the following 67-73.

66. (4 points) With this setup, provide the general formula for the resistance of the thermistor, in terms of R and the corresponding voltage V_0 of the value from the analog pin A0.

67. (4 points) What is the resolution of the ADC?

68. (10 points) Suppose $R = 20$ KOhms and $\delta R = \pm 10$ Ohms. Let $V_0 = 3.0V$. Assuming the ADC resolution is the only factor contributing to uncertainty in V_0, what is the uncertainty of the calculated thermistor resistance?

69. (4 points) What happens if you switch to a 12-bit ADC? Do you expect there to be an improvement in uncertainty? Why or why not? Find the new uncertainty of the thermistor resistance.

70. (4 points) What happens if you switch to using the 3.3V reference while keeping a 12-bit ADC (assume V_0 changes accordingly)? Do you expect there to be an improvement in uncertainty? Why or why not? Find the new uncertainty of the thermistor resistance.

71. (4 points) Now, you upgrade your resistor such that the new uncertainty is only 5 Ohms. Do you expect there to be an improvement in uncertainty? Why or why not? Find the new uncertainty of the thermistor resistance.

72. (4 points) Explain another way you can improve the uncertainty of the calculated thermistor resistance.

73. (10 points) Now, you are ready to start taking measurements so that you can convert the calculated thermistor resistance into measured temperature values. You take the following 5 data points:

Temperature (°C)	Resistance (Ohms)
84.0	1.46
60.2	4.90
39.4	11.36
21.0	38.09
4.6	167.34

Unfortunately, your calculator is only capable of using a linear regression to model the data. Can you still use it to predict temperature? If so, describe the necessary process and find the appropriate linear model. If not, explain why, and provide an alternative temperature sensor that you can use instead.

```
1  #define THERMISTORPIN A0
2  #define SERIESRESISTOR 10000
3  #define NUMSAMPLES 20
4  int samples[NUMSAMPLES];
5  float T;
6  int A = 0.0000186152, B = -0.000495746, C = 0.00464322;
7  void setup(void) {
8    Serial.begin(9600);
9    analogReference(EXTERNAL);
10 }
11
12 void loop(void) {
13   uint8_t i;
14   float x;
15   for (i=0; i< NUMSAMPLES; i++) {
16       samples[i] = analogRead(THERMISTORPIN);
17       delay(10);
18   }
19
20  x = 0;
21   for (i=0; i< NUMSAMPLES; i++) {
22       x += samples[i];
23   }
24   x /= NUMSAMPLES;
25
26   x = 65536 / x - 1;
27   x = SERIESRESISTOR / x;
28
29   T = 1.0/(A*log(x)*log(x)*log(x) + B*log(x) + C);
30   Serial.println(T);
31   delay(1000);
32 }
```

You have developed this Arduino code to interpret and display data from your temperature sensor.

74. (3 points) Point out one error in lines 1-10.

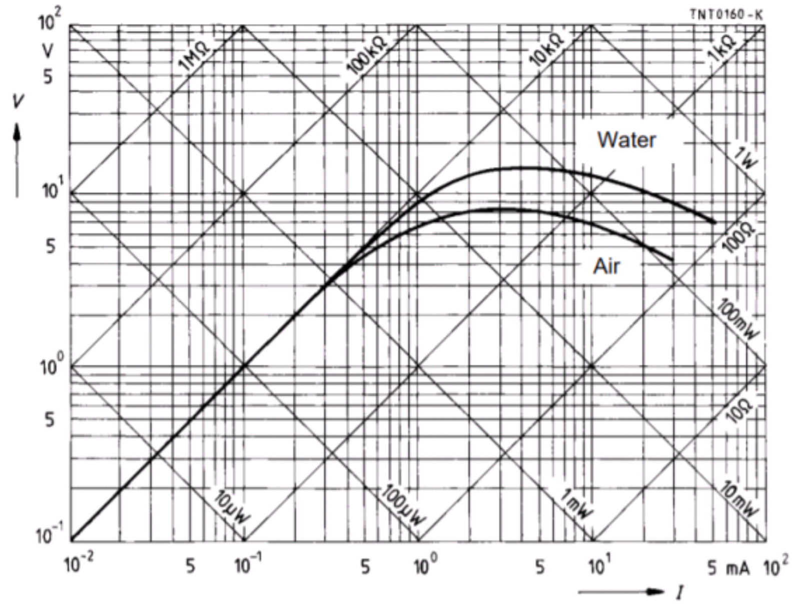
75. (3 points) What is the purpose of lines 20-24?

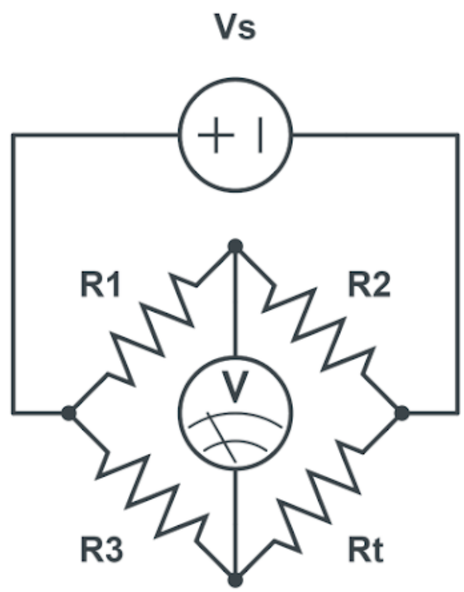
76. (3 points) How many bits does our microcontroller have?

77. (3 points) What are the final units for T?

78. (3 points) List 2 changes we can make to this code to meet the criteria for the Detector Building Event.

79. (8 points) Below is a voltage current characteristic of an NTC thermistor obtained at a constant temperature. The curve is initially linear with positive slope, then concave down with positive slope, and finally concave down with negative slope. At first glance, this is completely unanticipated, since we expect voltage and current to follow Ohm's Law. Reflect on the characteristic curve and provide an explanation for this behavior (be sure to interpret the point of maximum voltage).





For fun, you decide you want to try using a Wheatstone bridge as opposed to a standard voltage divider circuit. Rt denotes a 1 KOhm (at 25 °C) NTC thermistor with $\beta = 4000$. R1, R2, and R3 are resistors with resistances 500 Ohms, 700 Ohms, and 600 Ohms respectively. Vs is a 5V DC emf source.

80. (4 points) What is the voltage displayed by the voltmeter at 75 °C?

81. (4 points) If the voltmeter is replaced by a 750 Ohm resistor, find the power dissipated by the thermistor at 50 °C?