DETECTOR BUILDING C – KEY

UT SCIENCE OLYMPIAD INVITATIONAL TOURNAMENT 2021

TEAM ______________________ *example: Science Olympiad High School – Team Blue*	C - ______	
NAME(S) ______________ ______________		SCORE ______ / 222

INSTRUCTIONS	
1	You have up to 50 minutes to complete as many questions as you can on this exam.
2	As specified in the event rules, you are permitted to use, for reference, resources within a single 2-inch or smaller three-ring binder. With the exception of datasheets linked within this test, you may not consult the internet or other people beyond your partner for information.
3	Your entire score for this event is this Written Test. For this tournament, there are not Design Log or device components to the Total Score.
4	Please limit short answer responses to 1-4 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.
5	All tiebreaker questions are included in the test score and in the event of a tie will be used individually in the order specified.
6	There are no penalties for incorrect answers. Partial credit will be awarded for fill-in-the-blank and multiple answer (i.e. "select all that apply") questions.
7	Some questions ask that you input your answer as a rounded number and without units. It is very important that you follow these instructions or the auto-grade function will mark your answer as incorrect! For example, if you are instructed to enter your answer 12.3456 V in millivolts (mV) to the nearest millivolt, input "12346" for your answer. Also, Scilympiad checks for exact matches (ignoring upper and lower case) so if rounded to the nearest integer, do not follow your answer with a decimal, i.e. enter "60" and not "60."

NOTES	
1	This test was written for the UT Invitational hosted from October 23-24, 2020, by students at the University of Texas at Austin. This tournament was run in *mini SO* format with testing conducted via the Scilympiad platform. As such, many questions of this test were structured and/or worded for the online format.
2	This test was written by Abhi Dhir, a student at the University of Texas at Austin; Ryan Anselm, a student at the University of Texas at Austin; and George Sun, a graduate of the University of Washington in Seattle.

QUESTIONS		
1	**<u>Tiebreaker 9</u>: A 9 V battery is connected in series with a resistor and an LED in forward bias. If the recommended current and voltage for the LED are 20 mA and 3.2 V respectively, what resistance in ohms should be used for the resistor? Answer in ohms (Ω) rounded to the nearest ohm, and input your answer without units.** The closed loop equation is V_battery – V_LED – V_R = 0 which can be rewritten as R = (V_battery – V_LED) / I_R. By substituting the values provided by the question, we can determine that the resistor needed has a resistance of R = (9 V – 3.2 V) / (0.020 A) or 290 Ω. *3 points – correct answer (290)*	____ / 3
2	**What resistor color code corresponds to the resistance value from the previous question? Answer with the first three colors of the resistor color code in order (ignoring the tolerance band).** A resistance of 290 Ω corresponds to the following resistor color code: red, white, brown. *0.5 points – correct first color (red)* *0.5 points – correct second color (white)* *0.5 points – correct third color (brown)*	____ / 1.5

3	**Which of the following is/are true as more ideal bulbs are added in series to a circuit powered by a single ideal battery? Select all that apply.** **a. The brightness of individual bulbs increases as more bulbs are added to the series.** **b. The resistance of each bulb in the circuit increases.** **c. The current through the circuit decreases.** **d. The potential difference across all of the bulbs together in series remains unchanged.** **e. None of the above are correct.** a. The resistance of the circuit increases as more bulbs are added, so the brightness of individual bulbs should decrease. b. The resistance of individual bulbs should not change in response to other components in circuit under ideal circumstances. c. The resistance of the circuit increases so the current should decrease. d. All of the bulbs are powered by the same battery which is unchanged so the voltage across all bulbs altogether should be unchanged. e. Answer choices c. and d. are both correct. *1.5 points – for each answer choice correctly selected (c., d.) or not selected (a., b., e.)*	____ / 7.5
4	**What does the initialism LED stand for? Enter your answer as three separate words using only letters.** LED stands for "light-emitting diode." *0.5 points – first word is "light"* *0.5 points – second word is "emitting"* *0.5 points – third word is "diode"*	____ / 1.5
5	**Which of the following is NOT a type of LED?** **a. COB (chips-on-board)** **b. ABC (active button chips)** **c. SMD (surface-mount diodes)** **d. Through-hole packages** **e. All of the above are LEDs.** Active button chips are not a type of LED. COB, SMD, and through-hole are all different packages types that affect how components (in this case LEDs) are included in circuits. In COBs, the LED is directly bonded to the circuit board allowing for a very compact unit. Surface mount (SMD) allows mounting components directly to the surface of a circuit board; generally, SMD components are also smaller than through-hole. Through-hole typically requires holes in the circuit board to accept the component. The leaded LEDs you're probably using with a breadboard for your Detector Building device are examples of through-hole components. *2 points – correct answer (b.)*	____ / 2
6	**Which of the following is NOT an application of LEDs?** **a. Machine vision systems** **b. Water and air purification** **c. Data communication and signaling** **d. Measuring oxygen saturation** **e. All of the above are applications of LEDs.** a. Machine visions systems encompasses automated technologies that use imaging for inspection or analysis. LEDs have many uses in machine vision, the simplest of which is providing a consistent light source for imaging. b. UV-C is a common industrial method for biological disinfection of open spaces such as biological safety cabinets. UV-C LEDs also can be used for disinfecting water and air. c. Li-Fi or light fidelity is a technology that uses visible, ultraviolet, and/or infrared light for data transmission. LEDs are ubiquitous in signaling; your mobile phone and laptop likely have LEDs for indicating charging status or battery power. d. Pulse oximeters for measuring oxygen saturation typically employ red and green LEDs, which are two wavelengths at which oxygen-bound and unbound hemoglobin differ in absorbance profiles. e. All of the above are applications of LEDs. *4 points – correct answer (e.)*	____ / 4

7	**Which of the following is an advantage of LEDs compared to conventional light-emitting sources?** **a. LEDs have a lower initial cost per lumen.** **b. LEDs cause less light pollution compared to incandescent alternatives.** **c. LEDs do not cause blue-light hazard.** **d. LEDs are not dependent on ambient temperature.** **e. All of the above are disadvantages of LEDs.** a. LEDs are more complex than other light-emitting sources, making them more expensive initially. b. Compared to conventional light sources, LEDs emit more shorter wavelength light which produces a greater effect on light pollution. c. Related to the previous answer choice, high-energy short wavelength light contributes to blue-light hazard, which can cause retinal damage through prolonged exposure. d. LEDs are certainly dependent on ambient temperature: overheating an LED can significantly shorten its lifespan. e. This is the correct answer. All of the statements describe disadvantages to LEDs. *4 points – correct answer (e.)*	____ / 4
8	**Which of the following is NOT an advantage of LEDs compared to conventional light-emitting sources?** **a. LEDs do not contain harmful gasses.** **b. LEDs have less of an impact on insects when placed outdoors.** **c. LEDs can be dimmed or pulsed easily.** **d. LEDs are more shock resistant.** **e. All of the above are advantages of LEDs.** a. Fluorescent light bulbs (such as CFL and fluorescent tubes) contain mercury vapors that are harmful and can be released if the bulb is physically broken. LEDs can be and are typically made without mercury or lead. b. There is evidence that LEDs are more attractive to insects than conventional light-emitting sources. This effect has the potential to impact ecological networks by disrupting geographic distribution of insect populations. c. LEDs have faster response than conventional light-emitting sources. This allows LEDs to be pulsed at a frequency detectable by the human eye for a strobe effect or at a frequency higher than detectable by the human eye, which produces the effect of a dimmed bulb via pulse-width modulation. d. Compared to conventional light-emitting sources that involve long, delicate metal filaments (e.g. incandescent bulbs) or gases trapped in airtight cavities (e.g. halogen bulbs), LEDs are more shock resistant as they are constructed with solid state components (semiconductors). e. Answer choice b. is not an advantage of LEDs. *4 points – correct answer (b.)*	____ / 4
9	**Which of the following is implemented with several color emitters that are switched internally by varying voltages?** **a. Flashing LEDs** **b. Bi-color LEDs** **c. Digital RGB LEDs** **d. Filament LEDs** **e. Decorative-multicolor LEDs** Decorative-multicolor LEDs are implemented with several different color emitters. Colors are switched internally by varying supply voltages. *1 point – correct answer (e.)*	____ / 1
10	**Which of the following contains an integrated voltage regulator and a multivibrator?** **a. Flashing LEDs** **b. Bi-color LEDs** **c. Digital RGB LEDs** **d. Filament LEDs** **e. Decorative-multicolor LEDs** Flashing LEDs contain an integrated voltage regulator and multivibrator that cause the LED to flash at a regular frequency. *1 point – correct answer (a.)*	____ / 1

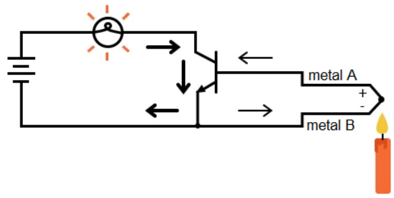
11	**Which of the following uses two dies that are connected to the same two leads which are antiparallel to each other?** **a. Flashing LEDs** **b. Bi-color LEDs** **c. Digital RGB LEDs** **d. Filament LEDs** **e. Decorative-multicolor LEDs** One type of bi-color LEDs uses two dies with two leads connected antiparallel to each other; current flow in one direction produces one color, while current in the opposite direction produces the other color. *1 point – correct answer (b.)*	____ / 1
12	**Which of the following involves connections in a daisy chain and contains control electronics that provide connections for data-in and data-out between nodes?** **a. Flashing LEDs** **b. Bi-color LEDs** **c. Digital RGB LEDs** **d. Filament LEDs** **e. Decorative-multicolor LEDs** Digital RGB LEDs are connected in a daisy chain where a common lead is shared by all colors while separate leads are used for each color of red, green, and blue. These are the four connections found on individual RGB LEDs and RGB LED strips. *1 point – correct answer (c.)*	____ / 1
13	**Which of the following contains multiple LED chips connected in series on a common longitudinal substrate?** **a. Flashing LEDs** **b. Bi-color LEDs** **c. Digital RGB LEDs** **d. Filament LEDs** **e. Decorative-multicolor LEDs** Filament LEDs mimic the appearance of the filament of incandescent bulbs by connecting many tiny LED chips in series such that they appear as a filament. *1 point – correct answer (d.)*	____ / 1
14	**What does the color rendering index (CRI) say about a light source?** **a. How many colors are shown when the light is on** **b. How accurately a light source reveals the true colors of objects when compared to how colors are shown in incandescent lighting or daylight** **c. The hue, tone, and temperature of white light emitted from a specific bulb or fixture** **d. Whether the bulb will be bright or dim when displaying particular colors** **e. None of the above are correct.** A color rendering index is a quantitative measurement for how accurately a light source (compared to ideal or natural lighting) reveals the true colors of objects. *3 points – correct answer (b.)*	____ / 3
15	**<u>Fill in the blanks</u>: The process of ________________ involves adding impurities to semiconductors to modify their optoelectric properties. A(n) ________-type material is a semiconductor with extra electrons (compared to holes), whereas a(n) ________-type material is a semiconductor with extra holes (compared to electrons).** The process of doping involves adding impurities to semiconductors to modify their optoelectric properties. An N-type material is a semiconductor with extra electrons (compared to holes), whereas a P-type material is a semiconductor with extra holes (compared to electrons). *2 points – correct first blank ("doping")* *2 points – correct second blank ("N")* *2 points – correct third blank ("P")*	____ / 6

16	**Which of the following dopants that would turn aluminum phosphide into a P-type semiconductor? Select all that apply.** **a. Zinc** **b. Boron** **c. Arsenic** **d. Selenium** **e. Beryllium** **f. Gallium** P-type semiconductors have an excess of holes (positive charge carriers) because the dopants used have fewer electrons in their valence (outermost) shell. Elements with fewer valance electrons than aluminum are to the left of it on the periodic table; these are beryllium and zinc. *0.5 points – for each answer choice correctly selected (a., e.) or not selected (b., c., d., f.)*	____ / 3
17	**Gallium nitride (GaN) has a band gap of 3.4 eV (5.45 × 10^-19 J). What wavelength in nanometers does this correspond to? Answer in nanometers (nm) with two significant figures, and input your answer without units.** Using the Planck equation, E = hc / λ (where E is the energy of a photon, h is Planck's constant, c is the speed of light in a vacuum, and λ is the wavelength of the photon), we can solve for wavelength. With h = 6.6 × 10^-34 J s and c = 3.00 × 10^8 m/s, we have λ = (6.6 × 10^-34 J s) * (3.00 × 10^8 m/s) / (5.45 × 10^-19 J) = 3.63 × 10^7 m or approximately 360 nm. *3 points – correct answer (360)*	____ / 3
18	**When the positive end of a circuit is connected to the N-type layer and the negative end is connected to the P-type layer of an LED, what is the resulting effect on the depletion zone?** **a. The depletion zone becomes smaller.** **b. The depletion zone remains unchanged.** **c. The depletion zone becomes larger.** **d. The depletion zone initially becomes smaller, then becomes larger over time.** **e. The depletion zone initially becomes larger, then becomes smaller over time.** Connecting the positive end of the circuit to the N-type layer and the negative end to the P-type layer puts the LED in reverse bias. Applying a voltage in this way forces negative charge carriers further into the negative side (the N-type layer) and positive charge carriers further into the positive side (the P-type layer). This further depletes the depletion zone, making it larger. *4 points – correct answer (c.)*	____ / 4
19	**Tiebreaker 7: For the previous question about depletion zones, explain why the resulting effect you selected occurs.** Connecting the positive end of the circuit to the N-type layer and the negative end to the P-type layer puts the LED in reverse bias (2 points). Applying a voltage in this way forces negative charge carriers further into the negative side (the N-type layer) and positive charge carriers further into the positive side (the P-type layer). This further depletes the depletion zone, making it larger (4 points). Award up to 2 additional points for thoroughness. *2 points – understanding that the diode is in "reverse bias"* *2 points – correct effect on N-type layer* *2 points – correct effect on P-type layer* *2 points – for very thorough answers*	____ / 8
20	**What are the analogues to the valence band and the conduction band respectively in OLEDs (organic LEDs)? Answer using only letters and no spaces or hyphens.** In semiconductors, the valence band is the lower energy orbital from which electrons can jump into the conduction band, the higher energy orbital. These are analogous to the highest-unoccupied molecular orbital (HOMO, which is lower energy) and the lowest-unoccupied molecular orbital (LUMO, which is higher energy). Together, HOMO and LUMO form the HOMO-LUMO gap which is essentially also a band gap. *1.5 points – correct first blank ("HOMO")* *1.5 points – correct second blank ("LUMO")*	____ / 3

21	**In which color or wavelength of LED will the cathode current increase the slowest as forward voltage increases?** **a. Red** **b. Blue** **c. Infrared** **d. Orange** **e. The current for all wavelengths of LEDs increase at the same rate.** According to the Planck equation, E = hf, each photon of a shorter wavelength light source has higher energy. Therefore, a shorter wavelength light source requires a greater voltage for a similar current. Of the options presented, blue light has the shortest wavelength. *3 points – correct answer (b.)*	____ / 3
22	**A patent filed in 1962 for a "semiconductor radiant diode" describes the mechanisms of early infrared LEDs. For this design, it was important to reduce absorption by minimizing the thickness of the ______________________________ which would increase the ______________________________.** A patent filed in 1962 for a "semiconductor radiant diode" describes the mechanisms of early infrared LEDs. For this design, it was important to reduce absorption by minimizing the thickness of the P-type region which would increase the absolute resistance to lateral current flow. *2 points – correct first blank ("P-type region")* *2 points – correct second blank ("absolute resistance to lateral current flow")*	____ / 4
23	**<u>Tiebreaker 6</u>: Which of the following statements about LEDs or temperature-sensing components is/are true? Select all that apply.** **a. Self-heating effects of LEDs increase their brightness and contribute to their electrical efficiency.** **b. Thermistors that increase current in response to increased temperature are prone to thermal runway.** **c. The current through a resistance temperature detector at a given temperature is dependent on its size and metallic makeup.** **d. LEDs are usually more compact than incandescent bulbs, with higher brightness and lower heat output by area.** **e. Self-heating effects are least pronounced when the thermal mass of the sensor and subject are small.** **f. None of the above are correct.** a. This statement is incorrect. Self-heating is detrimental to the lifespan of LEDs and therefore LEDs with high power ratings often require proper thermal management. b. This statement is true. A thermistor that increases current (by decreasing resistance) in response to increased temperature can experience thermal runway, a case of positive feedback where the device's own temperature increase contributes to further increases in temperature via increases in current. c. This statement is true. Electrical properties (resistivity and therefore current at a given voltage) are dependent on physical characteristics (e.g. length and cross-sectional size) and material properties (i.e. metallic makeup). d. This statement is true. The light-emitting parts of LED bulbs usually only occupy a small portion of the bulb's volume (compared to a typical incandescent bulb). LEDs also use less energy overall and a much higher percentage of their energy consumption for light production compared to incandescent bulbs which waste a majority of their energy consumption as heat. e. This statement is incorrect. A sensor with small thermal mass will be affected more by heat from its operation, possibly resulting in greater error. f. Answer choices b., c., and d. are all correct. *1.5 points – for each answer choice correctly selected (b., c., d.) or not selected (a., e., f.)*	____ / 9
24	**A functioning temperature-sensing device with a B value of 1832 K and R_50 value of 13.4 Ω is measured by an ohmmeter to have a resistance of 8.2 Ω. What is the temperature of the device? Answer in degrees Celsius (˚C) rounded to the nearest degree, and input your answer without units.** The B parameter equation for thermistors is given by 1 / T = 1 / T_0 + (1 / B) ln (R / R_0), where T represents temperature, R represents resistance, and B represents the β parameter that is specific to each thermistor. Using the values provided in the question allows solving for temperature: 1 / T = 1 / (273 + 50 K) + (1 / 1832 K) ln (8.2 Ω / 13.4 Ω). The temperature of the device is T = 354 K or 81˚C. *4 points – correct answer (81)*	____ / 4

25	**Which of the following factor(s) can affect the rate at which a temperature change is detected by a temperature-sensing device? Select all that apply.** **a. The size of the temperature-sensing element** **b. The thermal conductivity of the container in which the measured water is stored** **c. The sampling frequency of the temperature-sensing device** **d. The thermal conductivity of the material used to waterproof the temperature sensor** **e. The temperature of the room where the temperature-sensing device is used** **f. None of the above have an effect on the rate at which a temperature change is detected by a temperature-sensing device.** a. A large temperature-sensing element has more thermal mass, will be less susceptible to temperature fluctuations, and will take longer to detect a temperature change. b. While the container may affect the rate of temperature change of the water being stored, the sensor is still measuring the temperature of the water. c. A high sampling frequency to a degree will detect temperature chances faster compared to a lower sampling frequency. d. The thermal conductivity of the waterproofing material will affect how quickly the temperature change reaches the temperature-sensing element, thereby affect the rate at which the temperature change is detected. e. Again, while the temperature of the room may affect the rate of temperature change of the water being stored, the sensor is still measuring the temperature of the water. f. Answer choices a., c., and d. all can affect the rate at which a temperature change is detected by a temperature-sensing device. *1 point – for each answer choice correctly selected (a., c., d.) or not selected (b., e., f.)*	____ / 6
26	**<u>Tiebreaker 4</u>: For the previous question, explain how each of the answers you have selected affects the rate at which a temperature change is detected.** For each of the three correct answer choices, award 2 points for an explanation that describes how it affects the rate of temperature-sensing. Award 2 additional points overall for thoroughness. a. <u>The size of the temperature-sensing element</u>—A large temperature-sensing element has more thermal mass, will be less susceptible to temperature fluctuations, and will take longer to detect a temperature change. c. <u>The sampling frequency of the temperature-sensing device</u>—A high sampling frequency to a degree will detect temperature chances faster compared to a lower sampling frequency. d. <u>The thermal conductivity of the material used to waterproof the temperature sensor</u>—The thermal conductivity of the waterproofing material will affect how quickly the temperature change reaches the temperature-sensing element, thereby affect the rate at which the temperature change is detected. *2 points – for each answer choice correctly explained (a., c., and/or d.)* *2 points – for very thorough explanations*	____ / 8
27	**Of the following pairs of materials and starting temperatures, which has the slowest rate of increase in resistance given a linear increase in temperature?** **a. Gold, starting at 10 Kelvin** **b. Aluminum, starting at 100 Kelvin** **c. Tungsten, starting at 200 Kelvin** **d. Platinum, starting at 400 Kelvin** **e. Nichrome, starting at 500 Kelvin** As temperature increases, the rate of increase in electrical resistivity increases (temperature-resistance curves are not straight lines; they "smile"). Therefore, the material starting at the lowest temperature will experience the slowest rate of increase in resistance as temperature increases. This supports answer choice a. *3 points – correct answer (a.)*	____ / 3

28 **What is the name of the physical effect that governs the temperature sensor depicted? Answer with a single word.** ____ / 3



The depicted temperature sensor shows two dissimilar metals (metals A and B) which when heated produce an electric potential (as evidenced by the arrows indicating current flow and the light turning on as current is passed to the base of the NPN transistor). This is temperature-electricity phenomenon is described by the Seebeck effect.

3 points – correct answer ("Seebeck")

29 **Given a silver resistor with a resistance of 10.5 ohms at an initial temperature of 5.42°C, to what temperature does the resistor need to be heated in order for its final resistance to be 12.3 ohms? Use the temperature coefficient of silver as 3.80 × 10^-3/°C.** ____ / 3

a. **32.7°C**
b. **50.5°C**
c. **-8.20°C**
d. **44.1°C**
e. **None of the above are correct.**

The temperature-dependence of a resistor is given by R(T) = R(T_0) * (1 + α ΔT) where R(T) is the function for resistance, T_0 is the reference temperature, and α is the temperature coefficient for the resistive material. Using the values provided in the question, we can solve for ΔT to determine the final temperature: 12.3 Ω = (10.5 Ω) * (1 + 3.80 × 10^-3/°C * ΔT). The required increase in temperature from 5.42°C is ΔT = 45.1°C, which results in a final temperature of 50.5°C.

3 points – correct answer (b.)

30 **The Steinhart-Hart equation models the resistance of a semiconductor at different temperatures and is given by 1 / T = A + B ln R + C (ln R)^3. Which of the following is/are sufficient to characterize the Steinhart-Hart coefficients A, B, and C for an NTC thermistor? Select all that are sufficient.** ____ / 7.5

a. **The B parameter for the thermistor used as well as a temperature and resistance reading**
b. **The electrical conductivity of the semiconductor used and the specific heat of the semiconductor**
c. **The thermal conductivity of the electrodes used and the electrical impedance of the thermistor**
d. **Three pairs of temperature and resistance readings**
e. **None of the above are sufficient.**

a. The B parameter equation is a specific case of the Steinhart-Hart equation for NTC thermistors where A = 1 / T_0 – (1 / B) ln R_0, B = 1 / β, and C = 0. Therefore, the B parameter and a temperature/resistance reading are sufficient for determining A, B, and C.
b. These quantities cannot be used to solve for the Steinhart-Hart coefficients.
c. These quantities cannot be used to solve for the Steinhart-Hart coefficients.
d. This is the general method for solving for the Steinhart-Hart coefficients. Three pairs of temperature and resistance readings can be used to solve for the three unknown values, A, B, and C.
e. Answer choices a. and d. are both sufficient.

1.5 points – for each answer choice correctly selected (a., d.) or not selected (b., c., e.)

31 **<u>True or false</u>: In the thermistor equation, the B parameter, when solved for, is proportional to the natural log (ln) of the initial temperature plus the natural log of the final temperature.** ____ / 2

The B parameter equation for thermistors is given by 1 / T = 1 / T_0 + (1 / B) ln (R / R_0), where T represents temperature, R represents resistance, and B represents the β parameter that is specific to the thermistor used. Rearranging this equation to solve for B yields B = ln (R / R_0) / (1 / T – 1 / T_0). This does not support the statement in the question.

2 points – correct answer (false)

32	**<u>Tiebreaker 8</u>: How does resistance vary as temperature is decreased for an NTC thermistor?** **a. Resistance increases exponentially.** **b. Resistance increases linearly.** **c. Resistance remains the same.** **d. Resistance decreases exponentially.** **e. Resistance decreases linearly.** NTC (negative temperature coefficient) thermistors can be described using the B parameter equation, given by 1 / T = 1 / T_0 + (1 / B) ln (R / R_0), where T represents temperature, R represents resistance, and B represents the β parameter that is specific to the thermistor used. By the "NTC" descriptor, we already know that increases in temperature will cause decreases in resistance and vice versa. From the B parameter equation, we can see that temperature T varies directly with the natural log of resistance R. This means that as temperature is varied linearly, resistance will vary exponentially. *3 points – correct answer (a.)*	____ / 3
33	**Which of the following best describes an appropriate reason for using an epoxy thermistor over a glass thermistor?** **a. Epoxy thermistors are better suited for harsh environments.** **b. Epoxy thermistors are better suited for low-cost projects.** **c. Epoxy thermistors are better suited for environmental conservation.** **d. Epoxy thermistors are better suited for lower temperatures.** **e. Epoxy thermistors can be interchangeably used with glass thermistors.** The plasticity of an epoxy resin coating on a thermistor makes it better suited for lower temperatures. Glass is brittle and at low temperatures, thermal stress from the temperature differential between the operating component and the cold surroundings can cause cracks. *3 points – correct answer (d.)*	____ / 3
34	**No-contact thermometers are currently a popular choice for screening entrants for fever. Which one of the following sensors is most likely employed by such thermometers?** **a. NTC thermistors** **b. PTC thermistors** **c. Resistance temperature detectors** **d. Infrared thermometers** **e. Near-ultraviolet LEDs** Infrared thermometers are the best choice for contactless temperature measurements. The other options either require direct contact for an accurate measurement (thermistors and resistance temperature detectors) or are not methods for measuring temperature (near-UV LEDs). *2 points – correct answer (d.)*	____ / 2
35	**As a security feature, Apple's built-in FaceTime camera (the webcam) on MacBook laptops is engineered not to turn on unless the green LED adjacent to the camera is lit. Which of the following circuit arrangements would most likely allow this behavior?** **a. The camera and indicator LED in parallel with resistors added to each branch such that they have equal current** **b. The camera and indicator LED in series sharing a common input** **c. The camera and indicator LED in parallel with a Zener diode in the branch containing the camera** **d. A bipolar switch that directs current to the camera only if the indicator LED receives power** Only in the second case (a series circuit) does the camera powering on requiring a functional LED indicator. The rest of the answer choices are either nonfunctional or allow for the possibility of the camera turning on without the LED. (A bipolar switch is a toggle switch that requires physical user input, i.e. flipping the switch.) *3 points – correct answer (b.)*	____ / 3

36	<u>**Tiebreaker 3**</u>**: This question references the datasheet for Vishay's Silicon PIN Photodiode (https://www.vishay.com/docs/81503/bpv10nf.pdf). Which of the following statements is/are correct? Select all that apply.** **a. The photodiode should be used at 0.050 A with at most a potential difference of 1.3 V across the unit.** **b. In reverse bias, the photodiode will conduct electricity at voltages up to 60 V.** **c. The datasheet indicates that this photodiode contains elemental lead and therefore should be disposed of accordingly.** **d. The photodiode has a nominal diameter of 5 mm and will necessarily fit through an opening of 5 ± 0.15 mm.** **e. Sensing by the photodiode is wavelength-dependent and is most responsive in the infrared (IR) spectrum.** a. This is correct and is indicated by the "forward voltage" specification on page 2. b. This is incorrect. The "breakdown voltage" specification on page indicates the minimum voltage required for conduction in reverse bias. It may be confusing that it is called a maximum rating on page 1, but this is to indicate that it is a limit. c. This is incorrect. The datasheet indicates the product is free of elemental lead on page 1. The package type "leaded" indicates that the unit has metallic leads (as in "connections") for use with through-hole circuit boards or breadboards as opposed to surface-mount technology. d. This is incorrect. The schematic on page 4 shows that while the photodiode measures 5 ± 0.15 mm in diameter from its flat edge, the diameter specification perpendicular to this measurement is 5.75 ± 0.15 mm. e. This is correct. Page 2 of the datasheet indicates the "wavelength of peak sensitivity" is 940 nm, which corresponds to IR. Figure 6 on page 3 shows a wavelength-dependent sensitivity curve. *1.5 points – for each answer choice correctly selected (a., e.) or not selected (b., c., d.)*	____ / 7.5
37	**The analogRead function of the Arduino library reads voltages between 0 and 5 V as integer values between 0 and 1023, inclusive. What is the theoretical input voltage resolution of an Arduino circuit board? Answer in degrees millivolts (mV) rounded to the nearest 0.1 mV, and input your answer without units.** Integral measurements between 0 and 1023 correspond to 1024 "bins" which for a range of 5 V allow for a voltage resolution of 5 V / 1024 or 4.9 mV. *3 points – correct answer (4.9)*	____ / 3
38	**After collecting voltage readings across a range of temperature values, a student models their voltage-temperature curve as a linear relationship with the equation T = [(18.28 V^-1) * V - 13.37]˚C, where T corresponds to temperature in degrees Celsius and V corresponds to voltage in Volts. What is the temperature range their Arduino-based device can measure? Answer in degrees Celsius (˚C) rounded to the nearest degree, and input your answer without units.** At a minimum voltage of 0 V the device measures -13.37˚C, and at maximum voltage of 5 V the device measures 78.03˚C. This corresponds to a temperature range of 91.40˚C (or 91˚C rounded to the nearest degree). *3 points – correct answer (91)*	____ / 3
39	**What is the temperature resolution of the student's temperature-sensing device? Answer in degrees Celsius (˚C) rounded to the nearest 0.01˚C, and input your answer without units.** The Arduino's voltage resolution is 4.9 mV, which by the linear relationship provided allows a temperature resolution of [(18.28 V^-1) * 4.9 mV]˚C or 0.09˚C. *4 points – correct answer (0.09)*	____ / 4

40	**<u>Tiebreaker 1</u>: The following Python function is used to process an array containing all temperature readings before displaying a measured temperature on the digital display of a temperature-sensing device. Which of the following effects will occur when this function is used (compared to just displaying the latest reading unprocessed)? Select all that apply. (Do not worry if you are not familiar with Python; the variables are named and code commented such that you should be able to understand what is happening if you are familiar with another popular coding language.)**	____ / 9

```
# this function `report_temperature` takes as input an array of `temperature_readings`
that are ordered from oldest to latest
def report_temperature(temperature_readings):
   number_of_readings = len(temperature_readings)
   final_reading = 0

   if number_of_readings >= 5:
      # use the last five readings if there are five or more readings
      for temperature in temperature_readings[-5:]:
         final_reading += temperature / 5
   else:
      # otherwise use all the readings that are in the array
      final_reading = sum(temperature_readings) / number_of_readings

   return final_reading;
```

a. The temperature-sensing device will display temperature readings that are more stable.
b. Running these additional processor-intensive computational steps will cause overheating of the thermistor and introduce more error in temperature readings.
c. The temperature ranges in which each LED color turns on will be different.
d. The temperature-sensing device will take longer to respond to sudden temperature changes.
e. The temperature readings will be scaled to a constant reference value.
f. None of the above are correct.

The provided code takes a running average using the latest five temperature readings if there are five or more readings.

a. This is correct. A running average filter makes the signal less susceptible to noise.
b. This is incorrect. These computations are not intensive. Moreover, any temperature changes should occur at the microcontroller and not at the sensor end of the device.
c. This is incorrect. No lines in this function change colors of LEDs.
d. This is correct. A running average filter causes reported measurements to be affected by previous readings, making the signal respond slower to changes in value.
e. This is not correct. The above code takes a running average, which does not scale values to a constant reference.
f. Answer choices a. and d. are both correct.

1.5 points – for each answer choice correctly selected (a., d.) or not selected (b., c., e., f.)

41	**<u>Tiebreaker 2</u>: What are two steps that can be taken in data collection to ensure accuracy of a temperature-resistance model? How does each proposed step improve accuracy of the model?** Acceptable answers include: using more temperature-resistance pairs to determine the coefficients, using values from a wider range of temperatures and/or resistances, using a thermometer and/or ohmeter with verified accuracy (i.e. one that is calibrated to a reliable source). Answers will be scored for accuracy, appropriateness, and thoroughness, with up to 4 points per step offered: 2 points for each step, and 2 points for an explanation of how accuracy is improved. *2 points – for each valid step mentioned (up to 2 steps)* *2 points – for each accurate explanation (up to 2 explanations)*	____ / 8
42	**What does traceability mean in the context of calibration?** **a. The process by which an instrument can be redesigned to be made more accurate** **b. The process by which an instrument is aligned or balanced** **c. The process by which a measured value can be compared to a higher standard** **d. None of the above are correct.** In general, traceability describes the ability to trace or verify a detail. In the context of calibration, traceability describes the ability to compare measured values with a standard (a reference with verified accuracy). In this context, traceability is used to describe measured values (as described in answer choice c.) and not instruments (as in answer choices a. and b.). *3 points – correct answer (c.)*	____ / 3

43	**Which of the follow best describes a calibration standard?** **a. Another measurement device of known accuracy** **b. Another measurement device for correcting malfunction** **c. A device for reading physical properties of instruments** **d. A measurement device for adjusting alignments** **e. None of the above are correct.** A calibration standard is a device of known accuracy that can be used for verifying the performance of a less accurate device. This supports answer choice a. The calibration standard may be used for adjusting the less accurate device (as in answer choice d.) but this does not best describe a calibration standard. *3 points – correct answer (a.)*	____ / 3
44	**The General Electric (GE) Calibration Assessment Workflow is an organized process for performing calibrations and verifying results. What step follows if the answer to "As Left Calibration Pass?" is "No"?** According to the GE Calibration Assessment Workflow, the next step would be to "replace or repair equipment." *3 points – correct answer ("replace or repair equipment")*	____ / 3
45	**<u>True or false</u>: The standard instrument for calibrating a scale is a dead weight tester.** This is incorrect. Scales for weighing are typically calibrated with calibration weights. A dead weight tester checks the accuracy of pressure measurements. *2 points – correct answer (false)*	____ / 2
46	**Which of the following examples of linearization is/are correct? Select all that apply.** **a. A quadratic relationship can be linearized by taking the square root of both the independent and dependent variables.** **b. An exponential relationship can be linearized by taking the log of the responding variable.** **c. A power relationship can be linearized by taking the (multiplicative) inverse of the independent variable.** **d. An exponential relationship can be linearized by taking the exponent of the manipulated variable.** **e. None of the above are correct.** a. Applying the same mathematical operation to both independent and dependent variables does not linearize a model. Applying a square root to only the dependent variable or squaring only the independent variable would linearize a quadratic relationship. b. Logarithms are the mathematical inverse to exponents and can be used to linearize an exponential relationship. c. This is not correct. A power relationship is linearized by raising the dependent variable to a power that is the multiplicative inverse of the model's power. d. Applying the same function (in this case an exponent) to the manipulated variable is a valid method for linearization. e. Answer choices b. and d. are both correct. *1.5 points – for each answer choice correctly selected (b., d.) or not selected (a., c., e.)*	____ / 7.5
47	**<u>Tiebreaker 5</u>: A linear regression of a dataset yields an R-squared value of 0.98. Which of the following statements is/are necessarily true? Select all that apply.** **a. The relationship modeled must be a linear relationship.** **b. A linear relationship is a good approximation for the data.** **c. Exactly half of the points in the dataset will lie above the regression curve.** **d. The dataset follows a positive trend.** **e. None of the above are correct.** a. This statement is incorrect. A high R-squared does not indicate that the relationship modeled is correct. b. This statement is true. A high R-squared value does indicate a good fit. c. This statement is incorrect. Regressions attempt to minimize error of points from the curve, not balance points on one side or the other of a curve. d. This statement is incorrect. R-squared value tells us whether the trend is a good fit, not whether the trend is positive or negative. e. Answer choice b. is correct. *1.5 points – for each answer choice correctly selected (b.) or not selected (a., c., d., e.)*	____ / 7.5

48 **Which of the following reasons for linearizing non-linear experimental data is/are valid? Select all that are generally true.** ____ / 7.5

a. Linearizing allows verifying predicted mathematical relationships between variables.
b. Linear relationships are mathematically simpler to work with.
c. Linearized relationships usually involve units that are more intuitive.
d. Linearizing data ensures that collected data points are only increasing or only decreasing.
e. None of the above are correct.

a. This is generally true. As an example, an exponential relationship that may appear to be parabolic will only linearize when approached as an exponential relationship.
b. This is true. Linear equations can be manipulated with addition, subtraction, multiplication, and division.
c. This is generally untrue. The process of linearizing often produces units that are unintuitive (such as the natural log of degrees Celsius).
d. This is not an objective of linearization.
e. Answer choices a. and b. are both correct.

1.5 points – for each answer choice correctly selected (a., b.) or not selected (c., d., e.)

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49 **In a household kitchen, there are 2 appliances connected in parallel to a 50 Volt circuit: an 800-Watt toaster and a 1,200-Watt microwave. These appliances were designed and rated in a 20°C environment, but due to climate change, the ambient temperature has risen to 100°C. What is the minimum amperage (roundest to the nearest ampere) to which a circuit breaker should be set such that both appliances can be run at the same time at this new temperature, assuming both appliances contain copper filament resistors (which have resistivity 1.68 × 10^-8 Ω m and temperature coefficient 0.004/°C)?** ____ / 4

a. 11 amperes
b. 21 amperes
c. 31 amperes
d. 40 amperes
e. 45 amperes
f. None of the above are correct.

At 50 V and 20°C, the 800 W toaster will have a current of I = P / V = 800 W / 50 V = 16 A and the 1,200 W microwave will have a current of I = P / V = 1200 W / 50 V = 24 A. The resistivity of copper is proportional to its temperature in Kelvin, so the current will be inversely proportional to the temperature in Kelvin (by V = IR) at constant voltage. Therefore, at a higher temperature the 800 W toaster will have a current of 16 A * (293 K / 373 K) or 12.6 A and the 1,200 W microwave will have a current of 24 A * (293 K / 373 K) or 18.9 A. Because these two appliances are connected in parallel (where currents are added), the circuit breaker at minimum must be rated for the sum of these currents, 31.4 A.

4 points – correct answer (c.)

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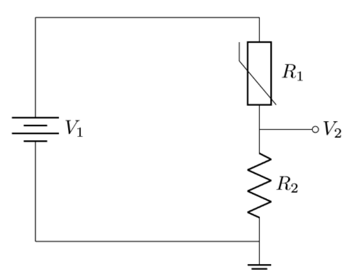
50 **What is the circuit element depicted below known as?** ____ / 3



The circuit element shown is known as a voltage divider. Voltage dividers allow an output (in this case V_2) that is a fraction of the input voltage (in this case V_1). As the resistance of the temperature-dependent resistor R_1 changes with temperature, the ratio of R_1 to R_2 will vary, changing the output of V_2.

3 points – correct answer ("voltage divider")

---

51 **Using the circuit diagram provided in the previous question, what is R_1 if R_2 = 4.7 kΩ, V_1 = 3.3 V, and V_2 = 1.4 V? Answer in kiloohms (kΩ) with two significant figures, and input your answer without units.** ____ / 3

For the voltage divider shown, the voltage of V_2 is given by V_1 * R_2 / (R_1 + R_2), which can be derived using Kirchhoff's loop rule. Using the values from the question, we have 1.4 V = 3.3 V * 4.7 kΩ / (R_1 + 4.7 kΩ), which when solved for R_1 yields R_1 = 6.4 kΩ.

3 points – correct answer (6.4)

52 **<u>True or false</u>: Resistance is inversely proportional to the cross-sectional area of a wire.** ____ / 2

The equation for resistance is given by $R = \rho L / A$ where ρ represents resistivity of the material, and L and A represent the length and cross-sectional area, respectively, of the resistor. This equation shows that resistance is inversely proportional to cross-sectional area.

2 points – correct answer (true)

53 **What is the resistance of a 20.0 m long platinum wire with a diameter of 2.05 mm. (If needed, assume that the resistivity of platinum is 9.80 × 10^-8 Ω m and the temperature coefficient of platinum is 3.92 × 10^-3/°C.) Answer in ohms (Ω) rounded to the nearest 0.01 Ω, and input your answer without units.** ____ / 3

The equation for resistance is given by $R = \rho L / A$ where ρ represents resistivity of the material, L and A represent the length and cross-sectional area, respectively, of the resistor. The wire is assumed to be cylindrical so its cross-sectional area is given by $A = \pi (d / 2)^2 = 3.3 \times 10^{-6}$ sq. meters. Using this with the values provided in the question, the resistance is $R = (9.80 \times 10^{-8}\ \Omega\ m) * (20.0\ m) / (3.3 \times 10^{-6}\ m^2)$ or 0.59 Ω.

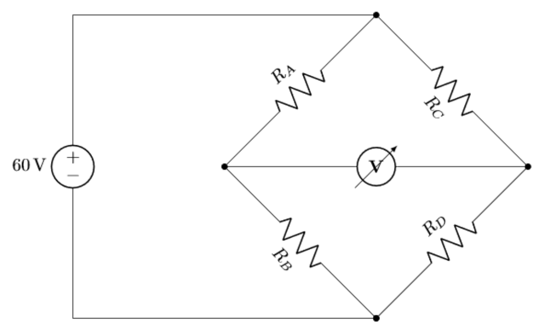
3 points – correct answer (0.59)

54 **Use the calculated value from the previous question (involving the platinum wire) as the initial resistance of the filament in a lightbulb. If the entire lightbulb increases in temperature by 52.1°C, what is the new resistance of the platinum resistor filament? (If needed, assume that the resistivity of platinum is 9.80 × 10^-8 Ω m and the temperature coefficient of platinum is 3.92 × 10^-3/°C.) Answer in ohms (Ω) rounded to the nearest 0.1 Ω, and input your answer without units.** ____ / 3

The temperature-dependence of a resistor is given by $R(T) = R(T_0) * (1 + \alpha \Delta T)$ where R(T) is the function for resistance, T_0 is the reference temperature, and α is the temperature coefficient for the resistive material. Using the values provided in the question, we can solve for the resistance at higher temperature: $R = (0.594\ \Omega) * (1 + 3.92 \times 10^{-3}/°C * 52.1°C = 0.7\ \Omega$.

3 points – correct answer (0.7)

55 **Consider the circuit shown above where at 20˚C, the voltage difference measured across the voltmeter is 3.00 V. Resistors A, B, C, and D are made of different materials with unique temperature coefficients of resistance (denoted by α). At 30˚C, the voltage difference measured across the voltmeter is -2.33 V. What are the resistance and temperature coefficients for resistor D? Enter your answers in this order. For resistance, answer in ohms (Ω) rounded to the nearest 1 Ω. For the temperature coefficient, follow the format shown in the table, rounding to the nearest 0.01. Input both answer without units.** ____ / 10



Resistor	Resistance at 20° C (Ω)	α
A	10	0.04
B	20	0.06
C	23	-0.03
D	?	?

This circuit is known as the Wheatstone bridge. The voltmeter measures the difference in the voltage across R_A and R_C or R_B and R_D. Using Kirchhoff's loop rule, we can show that at 20˚C, the voltage across R_A is 20 V and R_B is 40 V. If the voltage difference between R_B and R_D is 3.00 V as indicated in the question, the voltage must be 23 V across R_C and 37 V across R_D. For this to be true, with R_C = 23 Ω, R_D must be 37 Ω at 20˚C; this can be determined with the voltage divider equation, $37\ V = 60\ V * R_D / (R_C + R_D)$.

The temperature-dependence of a resistor is given by $R(T) = R(T_0) * (1 + \alpha \Delta T)$ where R(T) is the function for resistance, T_0 is the reference temperature, and α is the temperature coefficient for the resistive material. Using this equation, the resistances at 30˚C can be calculated for resistors A, B, and C: RA_{30} = 10 Ω * (1 + 0.04/˚C * 10˚C) = 14 Ω, RB_{30} = 20 Ω * (1 + 0.06/˚C * 10˚C) = 32 Ω, and RC_{30} = 23 Ω * (1 – 0.03/˚C * 10˚C) = 16.1 Ω. Now, the voltage across R_A is 60 V * 14 Ω / (14 Ω + 32 Ω) = 18.3 V and across R_B is 60 V – 18.3 V = 41.7 V.

If at 30˚C the voltmeter reads -2.33 V, then the voltage across R_D must now be 41.7 V – (-2.33 V) = 44.03 V. Again, using the voltage divider equation, 44.03 V = 60 V * RD_{30} / (RC_{30} + RD_{30}), we can determine that the resistance of R_D at 30˚C is 44.39 Ω. Using the equation for temperature-dependence of a resistor, 44.39 Ω = 37 Ω * (1 + α * 10˚C), it is determined that the temperature coefficient for resistor D is 0.02.

5 points – correct resistance (37)
5 points – correct temperature coefficient (0.02)