2025-2026 GullSO Invitational **Key**

Circuit Lab
KEY

December 13, 2025
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Exam Guidelines:

- You have 50 minutes to complete this exam, plus an extra 5-minute grace period at the end to organize your pages for submission. You will not be allowed to write anything during the grace period.
- You can take the test booklet apart (but you MUST put it back in order at the end).
- Point values are given for every question.
- Tiebreaker questions are denoted by the letters "TB".
- Write your answers on the provided answer sheet.
- **Grading notes:** Do *not* grade for significant figures unless specified. For any calculation whose answer is not a whole number, accept any value whose last digit is ± 5 of the last digit of the answer.

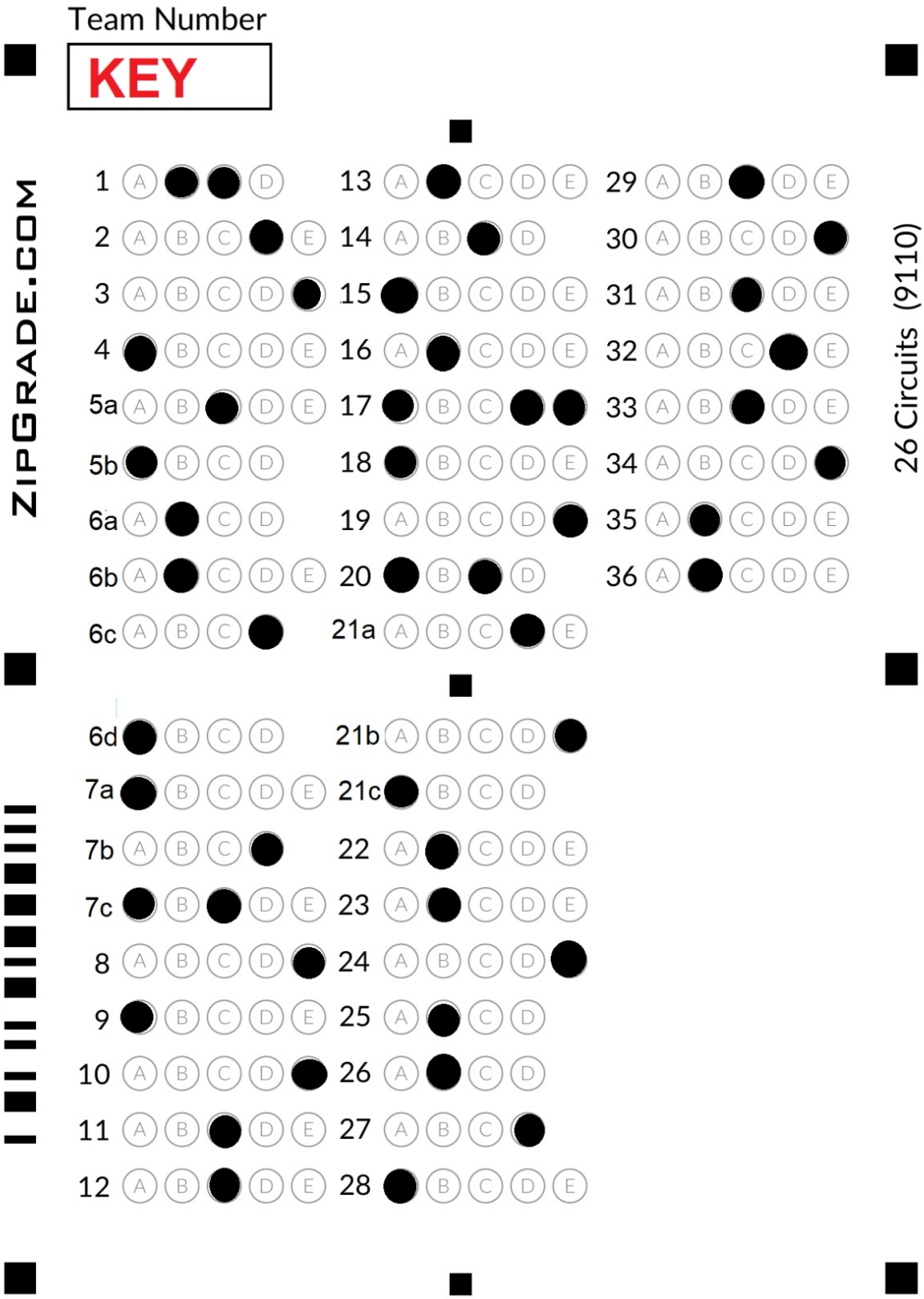
DO NOT TURN THE PAGE UNTIL INSTRUCTED

For grading use only

Page:	1	2	3	4	5	6	7	8	9	10	11
Points:	69	22	24	15	16	8	12	19	10	10	14
Score:											

Page:	12	13	14	15	16	17	18	19	20	21	Total
Points:	22	15	10	18	14	10	14	10	20	25	377
Score:											

1. (69 points)


Team Number
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ZIPGRADE.COM
26 Circuits (9110)
1 A B C D
2 A B C D E
3 A B C D E
4 A B C D E
5a A B C D E
5b A B C D
6a A B C D
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36 A B C D E

Free Response Questions

37. (a) (1 point) **Series**

(b) (1 point) 6Ω

(c) (1 point) **500 mA**

(d) (1 point) **500 mA**

(e) (3 points)

Solution: No (1) because the voltage drop across the resistor is >1 V (2)

(f) (2 points)

Solution: The $1\,\mathrm{M}\Omega$ (1) because it's the largest, minimizing the change in resistance, and thus is closest to the infinite resistance that is equivalent to not having a parallel resistor (1 for anything about how an open circuit is infinite resistance, this minimizes the change in resistance; 0.5 for just saying it's the biggest).

(g) i. (2 points) **1.33 A (1 for value)**

ii. (2 points) **1.33 A (1 for value)**

iii. (4 points)

Solution: $I_L = I_C = I_R = 0.25A$ (1 point for all 3 values being equal, 1 point for each correct value)

iv. (2 points) **m/n (all or nothing)**

38. (a) (1 point) **1000**

(b) (2 points)

Solution: Kirchhoff's current law/junction rule/first law

(c) (2 points) **7 A**

(d) (2 points) **9 A**

39. (a) (2 points)

Solution: $I_1 = I_2 = 0.2A$ **(1 for both being equal, 1 for either being the correct value)**

(b) (2 points) 2Ω **(2)**

(c) (3 points)

Solution: 20Ω **(3 points if correct, 1 point for attempt)**

(d) (1 point) **3/5 or .6 A**

(e) (1 point) **3/10 or .3 A**

(f) (1 point) **3/10 or .3 A**

(g) (1 point) **1/10 or .1 A**

(h) (1 point) **1/15 or 0.067 A**

(i) (2 points)

Solution: 108/25 or 4.32 Watts (1 for unit, 2 for answer)

40. **(TB #3)**

(a) (1 point) **Tesla(s)**

(b) (2 points) 10^4 **(no partial credit)**

(c) (1 point) **Same direction**

(d) (2 points) **D**

(e) (3 points)

Solution: 0.333 G, out of the page (2 for value, 1 for direction). 1 partial credit if they write 1 G

(f) (3 points)

Solution: 3.33 G, into the page (2 for value, 1 for direction). 1 partial credit if they write 2 G or 1.33 G

(g) (3 points)

Solution: 3 G, into the page (2 for value, 1 for direction). 1 partial credit if they write 1 G or 2 G

(h) (3 points)

Solution: 3.6 G, out of the page (2 for value, 1 for direction). 1 partial credit if they write 4 G

(i) (3 points)

Solution: $3.51 \cdot 10^{-21}$ **to the left N, out of the page (2 for value, 1 for direction).**

(j) (3 points)

Solution: 0 force applied (all or nothing because there is no force and thus no direction)

41. (a) (3 points)

Solution: $\frac{3-V_1}{6} = \frac{V_1-V_2}{6} + \frac{V_1-V_3}{8}$ **(1 point per term. If a term is on the opposite side, give 0.5 points instead)**

(b) (2 points) **12/7 or 1.714 V**

(c) (2 points) **15/14 or 1.071 V**

(d) (2 points) **6/7 or 0.857 V**

(e) (2 points)

Solution: 3/14 or 0.214 A (1 point for positive sign, 1 points for value). ONLY 1 point for 1/6 or 0.167 A

(f) (2 points)

Solution: 3/28 or 0.107 A (1 point for positive sign, 1 points for value). ONLY 1 point for 1/4 or 0.25 A

(g) (2 points)

Solution: 3/14 or 0.214 A (1 point for positive sign, 1 points for value). ONLY 1 point for 1/8 or 0.125 A

42. **(TB #1)**

(a) (1 point) **The 24Ω resistor in the top right**

(b) (1 point)

Solution: $\frac{1944}{505}$ or 3.850 V

(c) (1 point)

Solution: $\frac{1827}{505}$ or 3.618 V

(d) (1 point)

Solution: $-\frac{1176}{505}$ or 2.329 V

(e) (2 points)

Solution: $\frac{147}{505}$ or 0.291 A (1 point for value, 1 point for positive sign)

(f) (2 points)

Solution: $\frac{39}{505}$ **or 0.077 A (1 point for value, 1 point for positive sign)**

(g) (2 points)

Solution: $\frac{453}{2020}$ **or 0.224 A (1 point for value, 1 point for positive sign)**

(h) (2 points)

Solution: $\frac{609}{2020}$ **or 0.301 A (1 point for value, 1 point for positive sign)**

(i) Treat the 18Ω resistor as the load for the following subparts.

i. (3 points)

Solution: $\frac{308}{39}$ **or** $7.897\,\Omega$ **(no partial)**

ii. (3 points)

Solution: $\frac{308}{39}$ **or** $7.897\,\Omega$ **(1 point partial if equal to the previous answer)**

iii. (4 points)

Solution: $\frac{72}{13}$ or 5.538 V (partial credit: 2 for identifying that you remove the $18\,\Omega$ resistor, 1 for any positive voltage less than 9 V)

iv. (4 points)

Solution: $\frac{36}{35}$ or 1.029 A (partial credit: 2 for identifying that you replace the $18\,\Omega$ resistor with a short, 1 for any positive current)

43. (a) (1 point) **Wheatstone bridge**

(b) (2 points)

Solution: a (1), current/voltage difference across the 3Ω resistor is 0 (1)

(c) (1 point) **0 V**

(d) (1 point) **12/7 or 1.714 V**

(e) (2 points) **14/3 or 4.67 V**

(f) (2 points) **48/7 or 6.857 V**

(g) (2 points)

Solution: +2/3 or +0.667 A (1 point for sign, 1 point for value)

(h) (2 points)

Solution: +1/3 or +0.333 A (1 point for sign, 1 point for value)

(i) (2 points)

Solution: +12/7 or +1.714 A (1 point for sign, 1 point for value)

(j) (2 points)

Solution: -6/7 or -0.857 A (1 point for sign, 1 point for value)

(k) (2 points)

Solution: 24/7 or 3.429 A (1 point for sign, 1 point for value)

44. **(TB #2)**

(a) (2 points)

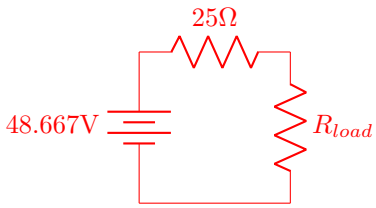
Solution: 25Ω (1 partial if given value is smaller than 50)

(b) (2 points)

Solution: 25Ω **(1 partial if equal to value for previous part)**

(c) (8 points)

Solution:



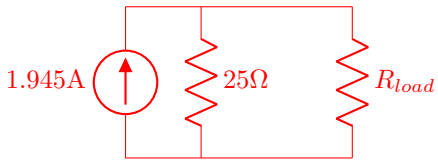
(should look like this with this voltage (48.667 V) and the resistance from the previous problem https://www.allaboutcircuits.com/uploads/thumbnails/Figure_2._Thevenin_equivalent_

(1 for having voltage source/battery, 1 for having resistor, 1 for them being in series, 2 for correct value of equivalent resistor, 3 for correct voltage: +1 partial if voltage is positive and an attempt was made, +1 partial if they show the load resistor was removed, +1 partial if there was either a 3 equation system of KVLs for supermesh or a 6 equation system of KCLs for supernode. NOTE: if the resistance of their resistor is equal to their answer for part (a), give both points for the equivalent resistor).

If they do not close the circuit and/or are missing the load resistor, still give full credit

(d) (8 points)

Solution:



(should look like this with this current (146/75 or 1.945 A) and the resistance from the first part `https://www.allaboutcircuits.com/uploads/thumbnails/Figure_2._Norton_equivalent_ci`
(1 for having current source, 1 for having resistor, 2 for them being in parallel, 2 for correct value of equivalent resistor, 5 for correct current: +1 partial if an attempt was made, +1 partial if they show the load resistor was replaced with a short, +1 partial if there was either a 4 equation system of KVLs for supermesh or a 6 equation system of KCLs for supernode. NOTE: if the resistance of their resistor is equal to their answer for part (b), give both points for the equivalent resistor)
If they do not close the circuit and/or are missing the load resistor, still give full credit

45. (a) (1 point)

Solution: $R_1 + R_2$ **or anything equivalent**

(b) (1 point)

Solution: $\frac{R_c(R_a+R_b)}{R_a+R_b+R_c}$ **or anything equivalent**

(c) (4 points)

Solution: $R_c = \frac{(R_a+R_b)(R_1+R_2}{R_a+R_b-R_1-R_2}$ **(4) (partial credit (only if final answer is wrong): 1 point for multiplying** R_1+R_2 **by** $(R_a+R_b+R_c)$**, 1 point for an attempt to simplify this expression (correct result is** $R_c(R_a+R_b) = (R_aR_1+R_bR_1+R_aR_2+R_bR_2)+R_c(R_1+R_2)$**, but anything close can earn the point). Give at most 2 points for an +answer which has** R_c **terms on both sides)**

46. (a) (2 points) **20 ms (1 for value, 1 for unit - any equivalent unit/value pair is fine too)**
    (b) (2 points) **6 mA or .006 A**
    (c) (2 points) **37% of the original current**
    (d) (3 points) $76\mu C$
    (e) (2 points) **0 A**

47. (a) (2 points)

Solution: $Q = CV$, **so** $Q_{C1} = 10\mu\text{F} \cdot 5\text{V} = 50\mu\text{C}$ **(1pt).** $Q_{C2} = Q_{C3} = 0$ **(1pt).**

(b) (3 points)

Solution: $V_a = \frac{50\mu\text{C}}{C_1 + (C_2 || C_3)} = \frac{50\mu\text{C}}{12.4\mu\text{F}} = 4.03\text{V}$

(c) (4 points)

Solution: $Q_{C1} = C_1 \cdot V_a = 40.3\mu\text{C}$ **(2pts),** $Q_{C2} = Q_{C3} = (C_2 || C_3) \cdot V_a = 9.7\mu\text{C}$ **(2pts)**

(d) (2 points)

Solution: $V_b = Q_{C3}/C_3 = 9.7\mu\text{C}/6\mu\text{F} = 1.62\text{V}$

(e) (5 points)

Solution: No (1pt), both C_2 and C_3 gain a charge for every charge that moves from C_1, since C_2 and C_3 are in series, so charge appears to increase (2pts). These charges come from a charge separation on the plates between C_2 and C_3, where positive charges accumulate on one plate and negative charges on the other. (2pts). Also acceptable: Yes (1pt), because the net charge here is always zero and only redistributed (2pt). When the switch is closed, positive charges move from C_1 to C_2, causing negative charge to build up on the other plate, causing positive charge to build up on C_3, causing negative charge to build up on the other plate, moving positive charges back to C_1. (2pt)

48. (a) (4 points)

Solution: $B = \mu_0 nI = \mu_0(500/0.01)(3) = 0.188\text{T}$

(b) (2 points)

Solution: from right-hand rule: curl fingers counter-clockwise, thumb points out of the page

(c) (2 points)

Solution: it does not experience a force, the magnetic field is constant and the charge is stationary.

(d) (2 points)

Solution: 0, it does not experience a force

(e) (4 points)

Solution: $\frac{\Delta B}{\Delta t} = \mu_0 n \frac{\Delta I}{\Delta t} = \mu_0 (500/0.01)(2) = 0.126\text{T/s}$

(f) (2 points)

Solution: feels a force down - the increasing magnetic field out of the page creates a clockwise electric field

(g) (4 points)

Solution: $3.15 \times 10^{-3}\text{N}$ **:** $E = -\frac{r}{2} \cdot \frac{\Delta B}{\Delta t}$, $F = QE = (0.5)(.1/2)(0.126) = 3.15\text{mN}$

Hands-On Tasks

49. (a) (4 points)

Solution: 4 points for building any working circuit on the breadboard

(b) (4 points)

Solution: answers may vary, but a typical answer may be a voltage divider with a known and unknown resistor in series. 4 points for a valid schematic with at least 3 components, -0.5pt per unlabeled component

(c) (6 points)

Solution: 3 pts for reasonable justification for component values, 3 pts for discusson on configuration

(d) (4 points)

Solution: measurements should only be voltages in the circuit, -1pt for incorrect sig-figs

(e) (4 points)

Solution: 3 pts for correct value from voltage measurements and known resistances, 1 pt for correct sig figs in the mystery resistor. note that known resistances are to the specified tolerance

(f) (4 points)

Solution: 2 pts for correct measurement (56 ohm), 2 pts for correct error

(g) (6 points)

Solution: 3 pts for reasonable sources of errors, 3 pts for reasonable improvements

50. (a) (1 point) **50 mA**

(b) (3 points)

Solution: 2.6V (1pt), forward current of 20mA (1pt) and ambient temperature of 25°C (1pt)

(c) (2 points)

Solution: no (.5pt), this would put 3V across the LED and cause a high current to flow (1pt), which can shorten the lifespan or even burn out the LED (.5pt).

(d) (2 points)

Solution: schematic should have a battery (.5pt), resistor (.5pt) in series (.5pt) with the LED (.5pt)

(e) (2 points)

Solution: current-limiting resistor (1pt) is in series (1pt) with the LED, since the LED voltage is fixed, the resistor takes the rest of the voltage drop.

(f) (1 point)

Solution: $\frac{3\text{V}-2.1\text{V}}{20\text{mA}} = 45\Omega$

(g) (1 point)

Solution: 47Ω **resistor**

(h) (4 points)

Solution: 4 points for building it

(i) (4 points)

Solution: $\frac{3.2\text{V}-2.1\text{V}}{47\Omega} = 23\text{mA}$ **(2pt),** $\frac{2.9\text{V}-2.6\text{V}}{47\Omega} = 6.4\text{mA}$ **(2pt)**

(j) (2 points) $\approx 37.5\text{mA}$

(k) (2 points)

Solution: no, max current @ 70C is 30mA

(l) (2 points)

Solution: $\frac{3\text{V}-2.1\text{V}}{37.5\text{mA}} = 24\Omega$ **(1pt),** 22Ω **(1pt)**

(m) (4 points)

Solution: 4 pts for correctly measuring the current.

(n) (4 points)

Solution: 4 pts for reasonable answer

51. (a) (5 points)

Solution: Schematic should have a battery or some kind of labeled input voltage (1pt), two resistors in series as a divider (1pt), a labeled output between those (1pt), and a labeled (1pt) load resistor connected in parallel to one of those resistors (1pt).

(b) (5 points)

Solution: answers may vary, should be something like $V_{out} = V_{in} \cdot \frac{R_2||R_L}{R_1+(R_2||R_L)}$ where $R_2||R_L = \frac{R_2 R_L}{R_2+R_L}$. 2 pts for a correct voltage divider formula, 3 pts for correctly including the load resistor.

(c) (4 points)

Solution: 2 pts for resistors in a ratio of 5:7, 2 pts for 22Ω and 15.7Ω or less.

(d) (6 points)

Solution: answers may vary, the best way would be a 22Ω with a 22Ω in parallel with a 56Ω. 1pt for labeling input/output, 5 pts for the ideal circuit. Give 4 pts for an attempt at approximating ideal values, 2 pts for any voltage divider using the given resistors, and 0 pts for including resistors that were not provided.

(e) (4 points)

Solution: 4 points for building the circuit they drew

(f) (4 points)

Solution: 2 pts for a measured input voltage, 2 pts for a measured output voltage, -1pt for incorrect sig-figs

(g) (2 points)

Solution: 2 pts for a correctly measured output voltage

(h) (4 points)

Solution: 4 points for voltages across each resistor, -1pt for each missing/incorrect measurement

(i) (5 points)

Solution: 5 points for correct calculations, -1pt for incorrect sig-figs

(j) (6 points)

Solution: 2 pts for discussing whether or not the design meets the spec, 4 pts for discussing at least two sources of error e.g. resistor tolerance, input voltage variation