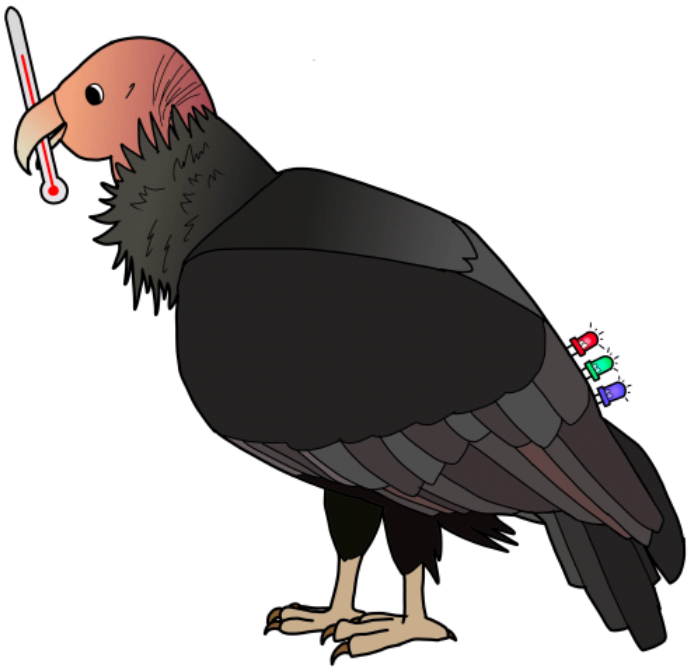
Detector Building C

BirdSO 2022 Mini

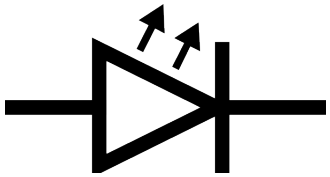
December 11th-18th, 2021



Directions:

- Work is not required on calculation questions, but partial credit will be given for work shown if the final answer is incorrect.
- Significant figures will not be checked. Ensure that your answers have enough precision to be distinguishable.

Use the following symbol representing a circuit element for the next 3 questions.



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

   A. Resistor

   B. Zener Diode

   C. Transistor

   D. Incandescent Light

   E. Light Emitting Diode

   F. Any source of light

2. (3 points) Which of the following are true of the point represented by the left side of the diagram?

   √ **It should be connected to positive voltage.**

   ◯ Connecting it to positive voltage will damage the component.

   ◯ It corresponds to the flat spot on the component.

   √ **It corresponds to the longer leg of the component.**

   ◯ It represents the direction that light is emitted in.

   ◯ It is known as the cathode.

3. (3 points) Which of the following are true of the point represented by the right side of the diagram?

   ◯ It should be connected to positive voltage.

   ◯ Connecting it to positive voltage will damage the component.

   √ **It corresponds to the flat spot on the component.**

   ◯ It corresponds to the longer leg of the component.

   ◯ It represents the direction that light is emitted in.

   √ **It is known as the cathode.**

4. (2 points) Two identical resistors are placed in series with a current source. The voltage drop across the pair of resistors is 5 V. What would the voltage across each resistor be if they were placed in parallel with the current source instead?

   A. 1.25 **V**

   B. 2.50 V

   C. 3.75 V

   D. 5.00 V

   E. 7.50 V

   F. 10.00 V

5. (2 points) What color of light corresponds to a wavelength of 656.28 nm?

   A. Infrared

   B. Red

   C. Green

D. Blue

E. Violet

F. Ultraviolet

6. (2 points) What color of light corresponds to a frequency of $3.14 \cdot 10^{14}$ Hz?

A. Infrared

B. Red

C. Green

D. Blue

E. Violet

F. Ultraviolet

7. (2 points) How much NaCl should be added to 150 mL of distilled water to create a solution with a concentration of 2000 ppm?

A. 0.03 g

B. 0.075 g

C. 0.3 **g**

D. 3 g

E. 7.5 g

F. 30 g

8. (2 points) Suppose that the volume of the dissolved ions in a 0.3 M solution of NaCl comprises 6% of the volume of the entire solution. What is the density of the solution?

A. 1.00 g/mL

B. 1.06 g/mL

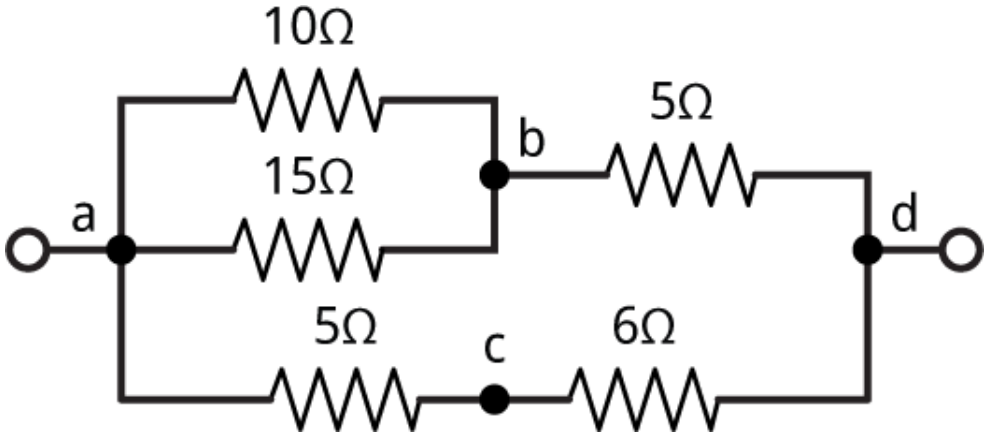
C. 1.12 **g/mL**

D. 1.18 g/mL

E. 1.24 g/mL

F. 1.30 g/mL

Use the following circuit diagram for the next 4 questions.



9. (2 points) What is the equivalent resistance of this network of resistors?

A. 1.4 Ω

B. 4.3 Ω

C. 5.5 Ω

D. 8.8 Ω

E. 10 Ω

F. 41 Ω

10. (2 points) If the network is connected to a 22 V source, what will be the voltage across the 6 Ω resistor?

A. 1 V

B. 2 V

C. 6 V

D. 12 V

E. 22 V

F. 44 V

11. (2 points) If the network is connected to a 110 V source, what will be the current through the 10 Ω resistor?

A. 3 A

B. 6 A

C. 10 A

D. 11 A

E. 22 A

F. 55 A

12. (2 points) If the network is connected to a 1 A source, what will be the power dissipated by the 5 Ω between points b and d?

A. 0.75 W

B. 1.00 W

C. 1.25 W

D. 2.00 W

E. 2.50 W

F. 5.00 W

13. (2 points) A conductivity meter measure the concentration of a solution of NaCl as 100 ppm. However, the conductivity meter was calibrated at a temperature of 298.15 K while the solution was at a temperature of $302.15K$. What is the true concentration of the solution?

A. 92 ppm

B. 96 ppm

C. 100 ppm

D. 104 ppm

E. 108 ppm

F. 112 ppm

14. (3 points) Which of the following semiconductors can be used to construct both red and green LEDs?

◯ Zinc selenide

√ **Gallium phosphide**

◯ Gallium arsenide phosphide

√ **Aluminium gallium indium phosphide**

◯ Gallium arsenide

◯ Aluminium gallium phosphide

15. (2 points) An ideal LED has a forward voltage of 2.718 V. What is the wavelength of light emitted by the LED?

A. 656 nm

B. 575 nm

C. 532 nm

D. 478 nm

E. 456 nm

F. 403 nm

16. (2 points) Which of the following is an accurate description of the luminous efficacy of an LED?

A. It is the ratio of the power used by an LED to the wavelength of light emitted.

B. It is a measure of how pure the spectrum of light emitted by the LED is.

C. It is the ratio of the power used by the LED to the power emitted in the form of visible light by the LED.

D. It is a measure of the attenuation of the light emitted by the LED.

E. It is a measure of the directionality of the LED's output.

F. It is the ratio of the luminous flux of the LED to its power.

17. (3 points) What is the name of the process that emits light in an LED? Your answer should be a single word.

electroluminescence

18. (3 points) Fill in the blanks.

The phenomenon described in the previous question takes place when a photon is emitted during **recombination** (1 word) when a(n) **electron** (1 word) joins with a(n) **electron hole** (2 words) and they are annihilated.

19. (2 points) Which of the following statements about efficiency droop is false?

A. It can be solved by placing more LEDs in the same bulb.

B. It is caused by the heat generated by the LED in operation.

C. It is correlated with a decrease in the lifetime of an LED.

D. It represents the decrease in luminous efficacy as the current through an LED increases.

E. It is of larger concern in high current situations.

F. It is caused by the Auger Effect.

For the next 2 questions, consider an 8-bit ADC that has a voltage measurement range of up to 5 V.

20. (2 points) If the ADC is used directly to measure a voltage that can vary between 0 V and 3.3 V, what is its voltage resolution?

A. 3.2 mV

B. 4.9 mV

C. 12.9 mV

D. 19.5 mV

E. 412.5 mV

F. 625 mV

21. (3 points) Which of the following changes will improve the voltage resolution?

◯ Decrease the bits from 8 to 6.

√ **Increase the bits from 8 to 10.**

√ **Replace the ADC with one that has a measurement range of** 0 **V to** 4 **V.**

◯ Replace the ADC with one that has a measurement range of 0 V to 6 V.

◯ Change the resistor used in the voltage divider so that the analog range is from 0 V to 2 V.

√ **Change the resistor used in the voltage divider so that the analog range is from** 0 **V to** 4 **V.**

22. (1 point) Suppose we use a 6-bit ADC with a measurement range of 0 V to 10 V and get a digital reading of 51. What voltage does this reading correspond to?

A. 5.1 V

B. 6.4 V

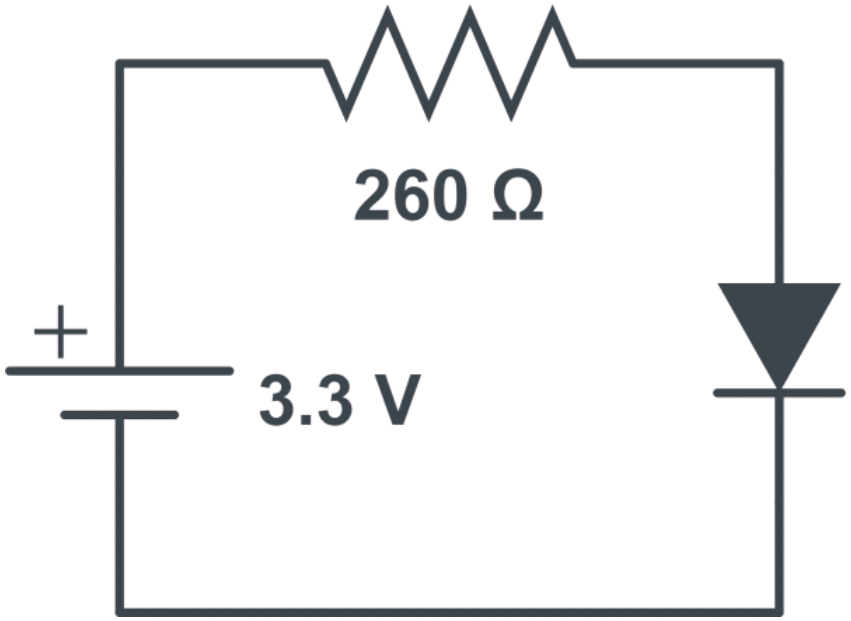
C. 7.5 V

D. 8.0 **V**

E. 8.1 V

F. 8.5 V

Use the follow circuit diagram for the next 4 questions. Assume that the diode has a forward voltage of 0.7 V.



23. (2 points) What is the current through the circuit?

A. 15.4 mA

B. 12.7 mA

C. 12.4 mA

D. 10.0 **mA**

E. 3.3 mA

F. 2.6 mA

24. (2 points) What is the power supplied by the battery?

A. 50.8 mW

B. 41.9 mW

C. 40.9 mW

D. 33.0 **mW**

E. 10.9 mW

F. 8.5 mW

25. (2 points) What is the power dissipated by the resistor?

A. 1.8 mW

B. 10.9 mW

C. 26.0 **mW**

D. 8.7 mW

E. 41.9 mW

F. 40.0 mW

26. (4 points) Where does this remaining power go?

Solution: Dissipated as heat in the diode.

27. (3 points) Which of the following compounds when placed in a 1 M solution will not conduct electricity?

◯ $NaCH_3COO$

√ $C_6H_{12}O_6$

◯ CH_3COOH

◯ $NaOH$

√ C_2H_5OH

√ CH_3OH

28. (3 points) Which of the following are weak electrolytes?

◯ HBr

◯ HI

√ HF

√ NH_3

√ H_2CO_3

√ HCOOH

29. (2 points) 0.01 M of which of the following compounds will result in the solution with the highest conductivity?

A. NaCl

B. NaBr

C. NaOH

D. $NaCH_3COO$

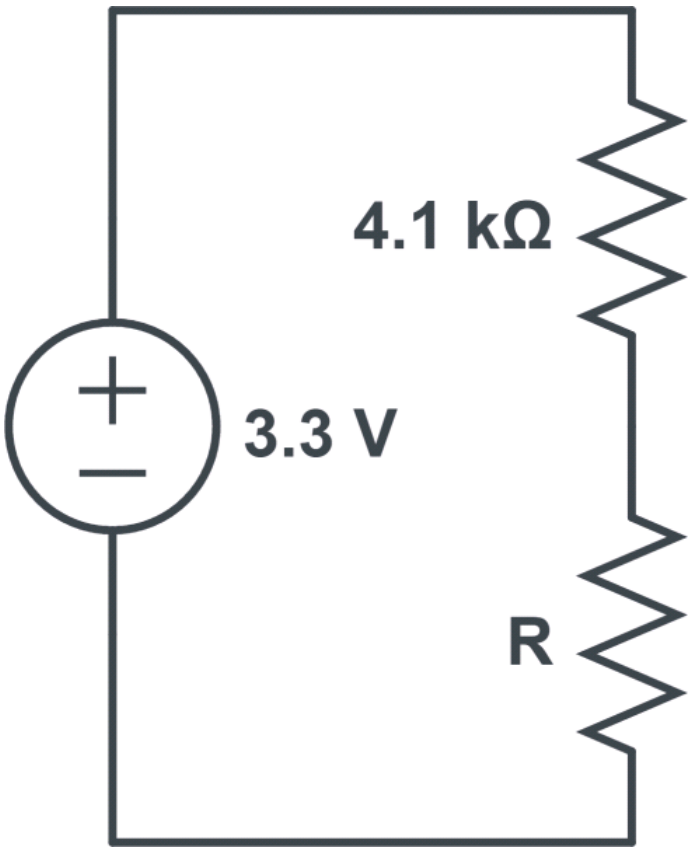
E. $NaNO_3$

F. NaF

30. (4 points) Will 1 M NaCl or 1 M $MgCl_2$ have a higher conductivity and why?

Solution: $MgCl_2$, as it has 2 M Cl^- compared to 1 M Cl^- in NaCl, and as Mg^{2+} has a higher conductivity than Na^+.

Use the following circuit diagram for the next 5 questions.



31. (4 points) Suppose that a voltmeter is connected across the 4.1 kΩ resistor.

Find the unknown resistance R in terms of the voltage reading V_{out}.

Solution:

$$V_{out} = 3.3\text{ V} \cdot \frac{4.1\text{ k}\Omega}{4.1\text{ k}\Omega + R} \implies R = 4.1\text{ k}\Omega \left(\frac{3.3\text{ V}}{V_{out}} - 1\right).$$

32. (6 points) Assume the voltmeter has an uncertainty of $\delta V_{out} = \pm 10$ mV and the unknown resistor has a resistance of $R = 3000\ \Omega$.

What voltage would the voltmeter read? What would the uncertainty in the calculated unknown resistance be?

Solution:

$$V_{out} = 3.3\text{ V} \cdot \frac{4.1\text{ k}\Omega}{4.1\text{ k}\Omega + 3.0\text{ k}\Omega} = 1.906\text{ V}.$$

$$\delta R = 4.1\text{ k}\Omega \cdot \frac{3.3\text{ V}}{V_{out}} \cdot \frac{\delta V_{out}}{V_{out}} = 37.26\ \Omega.$$

33. (4 points) Suppose the voltmeter is instead connected across the unknown resistor.

Find the unknown resistance R in terms of the voltage reading V_{out}.

Solution:

$$V_{out} = 3.3\text{ V} \cdot \frac{R}{4.1\text{ k}\Omega + R} \implies R = \frac{4.1\text{ k}\Omega}{\frac{3.3\text{ V}}{V_{out}} - 1}.$$

34. (6 points) Assume again that the voltmeter has an uncertainty of $\delta V_{out} = \pm 10$ mV and the unknown resistor has a resistance of $R = 3000\ \Omega$.

What voltage would the voltmeter read in this new scenario? What would the uncertainty in the calculated unknown resistance be?

Solution:

$$V_{out} = 3.3\text{ V} \cdot \frac{3.0\text{ k}\Omega}{4.1\text{ k}\Omega + 3.0\text{ k}\Omega} = 1.394\text{ V}.$$

$$\delta R = 4.1\text{ k}\Omega \cdot \frac{3.3\text{ V}}{(3.3\text{ V} - V_{out})^2} \cdot \delta V_{out} = 37.26\ \Omega.$$

35. (4 points) Now suppose that the exact resistance of the 4.1 kΩ is not known, but it has bands of color Yellow, Brown, Red, and Gold.

What is the new uncertainty in the calculated unknown resistance

Solution: $\delta R = \sqrt{(37.26\ \Omega)^2 + (5\% \cdot 3000\ \Omega)^2} = 154.6\ \Omega$.

Consider the following scenario for the next 3 questions. A conductivity meter is placed in high-concentration solution of NaCl. A DC voltage is applied across the two electrodes.

36. (3 points) Which of the following are true?

- ◯ The electrode connected to the positive end is the cathode.
- √ **The electrode connected to the positive end is the anode.**
- √ **A current will begin to flow.**
- ◯ An increase will occur at the anode.
- √ **Oxidation will occur at the anode.**
- ◯ Reduction will occur at the anode.

37. (4 points) List all of the products that will form at the anode and at the cathode. Also, list the products that could form yet are less favorable. Be sure to include the state of matter.

Solution: Anode: Cl_2 (g) [O_2 (g) is less favorable] Cathode: H_2 (g) [Na (s) is less favorable]

38. (4 points) How will the applied voltage affect the conductivity of the solution?

Solution: As Chlorine and Hydrogen gas are released, the solution approaches a solution of NaOH with the same concentration, which has a higher conductivity than NaCl. Thus, the conductivity will increase over time.

One way to fix the problem described in the previous section would be to use alternating current rather than direct current. However, this requires changing both the hardware and the software.

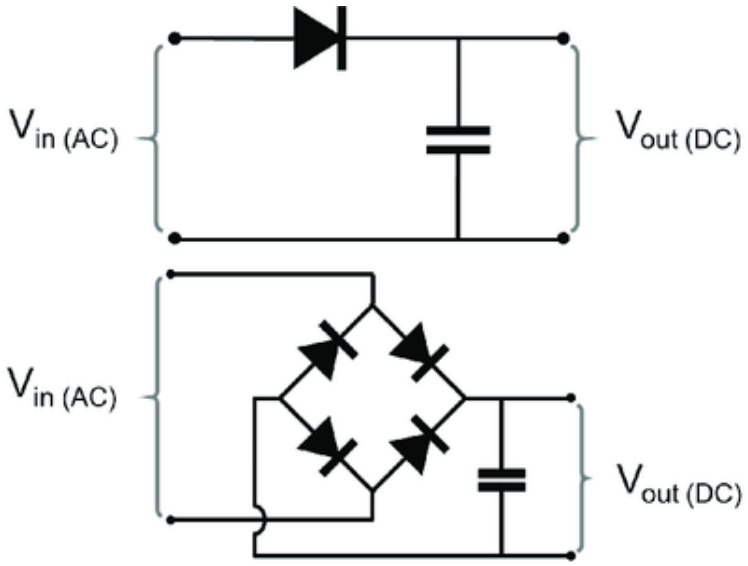
39. (4 points) There are multiple ways to implement AC output from an Arduino, but one way is to connect one electrode to half of the supply voltage (2.5 V) and the other electrode to a digital output that will alternate between low (0 V) and high (5 V). This will create an alternating voltage with an amplitude of 2.5 V. An attempt to implement the code is shown below. Explain why the code does not work as intended and explain how it can be modified to work.

```
void setup() {
    pinMode(12, OUTPUT)
}

void loop() {
    digitalWrite(13, LOW);
    digitalWrite(13, HIG);
}
```

Solution: Numerous typos: `pinMode` is missing a semicolon, `digitalWrite` uses the wrong pin number, `HIGH` is misspelled. Additionally, adding a `delay` after each `digitalWrite` can reduce the output frequency but make it more even.

In order to measure the AC signal, it is necessary to first convert the signal to DC. Here are two possible circuits to achieve this:



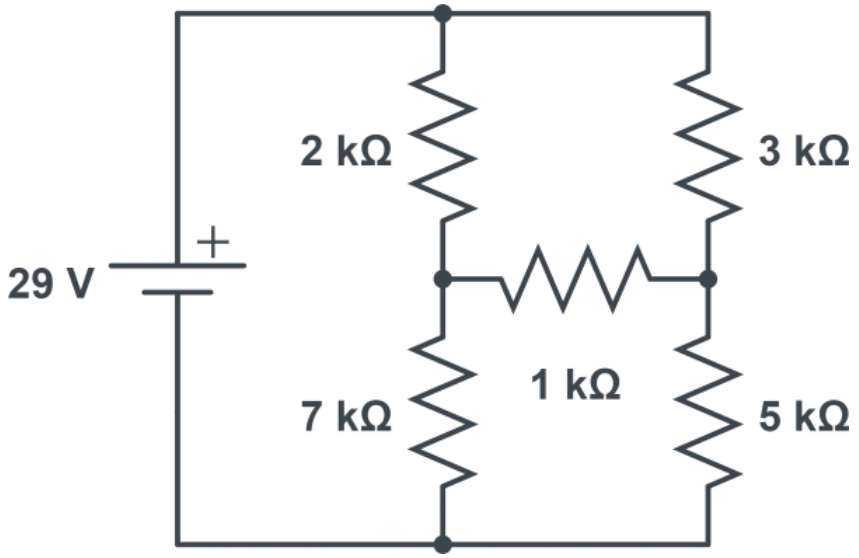
40. (4 points) What are these two circuits called and how do they differ?

Solution: Half wave rectifier and full wave/bridge rectifier. Half wave only converts the positive AC signal to DC while full wave converts both polarities.

41. (4 points) What is the purpose of the capacitor attached to both circuits?

Solution: To smooth out the ripples in the DC signal.

Use the following circuit diagram for the next 4 questions.



42. (4 points) What is the current through the battery?

Solution: After applying Delta-Wye,

$$1 + \frac{1}{1/(\frac{1}{3}+7) + 1/(\frac{1}{2}+5)} = 29/7 \text{ k}\Omega$$

is the equivalent resistance, for a current of

$$\frac{29 \text{ V}}{29/7 \text{ k}\Omega} = 7 \text{ mA}.$$

43. (4 points) What is the voltage across the 1 kΩ resistor?

Solution:

$$(29 \text{ V} - 7 \text{ mA} \cdot 1 \text{ k}\Omega)\left(\frac{7 \text{ k}\Omega}{7 \text{ k}\Omega + \frac{1}{3} \text{ k}\Omega} - \frac{5 \text{ k}\Omega}{5 \text{ k}\Omega + \frac{1}{2} \text{ k}\Omega}\right) = 1 \text{ V}.$$

44. (4 points) If the 1 kΩ resistor were removed, what would the voltage between its original endpoints be in the resulting circuit?

Solution:

$$29 \text{ V}\left(\frac{7 \text{ k}\Omega}{7 \text{ k}\Omega + 2 \text{ k}\Omega} - \frac{5 \text{ k}\Omega}{5 \text{ k}\Omega + 3 \text{ k}\Omega}\right) = \frac{319}{72} \text{ V} = 4.431 \text{ V}.$$

45. (4 points) Describe how a Zener diode can be used in a shunt regulator.

Solution: When placed in reverse bias in parallel with the load, the Zener diode will go into the Zener breakdown region if the voltage crosses its threshold. With an appropriate resistor, this leads to the voltage being effectively capped at the diode's Zener voltage.

46. (4 points) Describe what would occur if an ordinary diode were used instead of a Zener diode in the circuit from the previous question.

Solution: Once the diode passes its breakdown voltage and undergoes avalanche breakdown, it will undergo a hysteresis effect and will continue to conduct at lower voltage, which is not desired.

Use the following data for the next 2 questions.

x	y
0.2	2.81
0.4	3.18
0.6	3.29
0.8	3.53
1.0	3.61
1.2	3.71
1.4	3.83
1.6	3.85
1.8	3.93
2.0	3.94

47. (6 points) Perform a linear regression on the data. Your model should be in the form $y = a + bx$, and be sure to include the r^2 value for the line of best fit.

Solution: $y = 2.92733 + 0.582424x$, $r^2 = 0.9003$.

48. (6 points) The data does not appear to be linear in nature. Perform an appropriate transformation to linearize the data and then perform a linear regression on the resulting data set. Include the equation for your model in terms of x and y, and include the r^2 value from the line of best fit on the linearized data.

Solution: $\log y = 0.556561 + 0.149042 \log x \implies y = 3.602x^{0.149}$, $r^2 = 0.9914$. (Other transformations are possible)