

Ohm's Law

Recommended Equipment

- [D3000 - 9.5 DC Components Experiment Card](#)
- Digital multimeter with DC ranges of 20 mA, 200 mA and 20 V and resistance ranges of 2 k Ω and 20 k Ω
- Shorting links and connecting leads

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Ohm showed that there was a fixed relationship between voltage, current and resistance. He fixed the unit of resistance so that if you divide the voltage in volts by the current in amps, you get the resistance in ohms.

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$R = \frac{V}{I}$$

Note that the symbol used for the value of a current is **I**. (C is used for another electrical quantity, capacitance.)

The formula can be shown three ways, depending on what you already know and what you want to find out.

$$R = \frac{V}{I}$$

$$I = \frac{V}{R}$$

$$V = RI$$

This formula is probably the most important and significant one that you will ever meet in electronics. It keeps coming up. **Learn it.**

There is a useful little aid to memory, the resistance triangle:



To find the formula for resistance, cover the “R” in the triangle with the tip of your finger and the other side of the formula $\frac{V}{I}$ is seen.

In the same way, covering the I (for current) exposes $\frac{V}{R}$, and covering the V shows R.I.

If you know the applied voltage and the current through a resistor, then you can calculate the value of the resistor in Ω .

If a current of 4 mA flows when a supply voltage of 10 V is applied, then the resistance, R =

$$\frac{V}{I} = \frac{10}{4 \times 10^{-3}} = 2500 \Omega \text{ (2.5 k}\Omega\text{)}$$

1

Calculate and enter the value of a resistor (in k Ω) which allows a current of 3 mA to flow when a voltage of 12 V is applied.



k Ω (Enter your answer as a number and press return)

If you use the current formula with an applied voltage of 10 V you can find the value of current expected for a 680 Ω resistor.

$$\text{Current (I)} = \frac{V}{R} = \frac{10}{680} = 10 \div 680 = \mathbf{14.7 \text{ mA}}$$

2

Calculate and enter the current (in mA) expected if a supply voltage of 11 V is applied to a 2.2 k Ω (2200 Ω) resistor.



mA (Enter your answer as a number and press return)

The voltage formula $V = R \cdot I$ allows you to find the voltage across a resistor when a given current flows through it.

If a current of 2.5 mA flows through a 1 k Ω resistor then the voltage dropped across it must be: $V = R \times I = (1 \times 10^3) \times (2.5 \times 10^{-3}) = 2.5 \text{ V}$

(Note that the **k** prefix of the resistance cancels out the **m** prefix of the current.)

3

Calculate and enter the voltage across a 2.2 k Ω resistor when a current of 4 mA flows through it.



V (Enter your answer as a number and press return)

- **Before** connecting the circuit, switch ON the Power Supplies and set switch S1 to OFF, then set up the digital multimeter to the 20 V DC range and connect it across the variable DC power supply on the D3000 9.5 Experiment Card. Adjust the variable DC voltage control on the base unit for a supply voltage of 10 V, as measured on the multimeter.
- Disconnect the digital multimeter from the circuit. Select the 20 mA DC range and move the positive (red) lead to the socket marked mA or A. Now reconnect the multimeter into the circuit as shown in Fig 1.1, together with a 2 mm connecting lead to connect to the DC supply voltage.

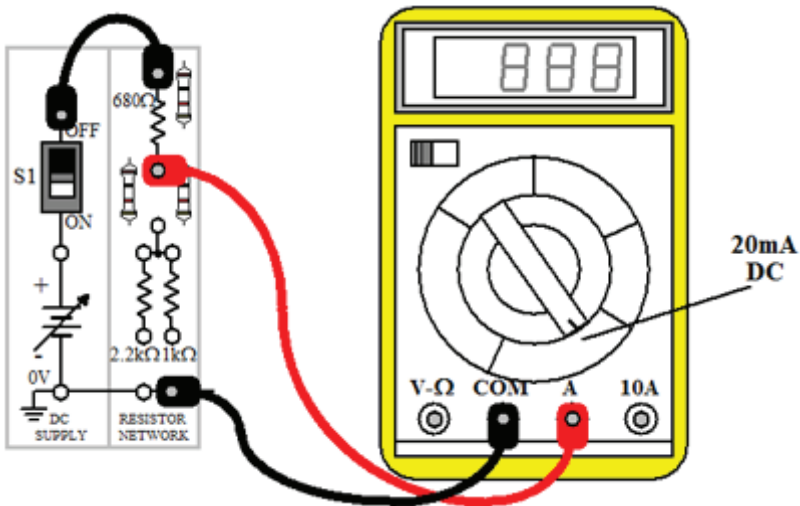


Figure 1.1

4 Enter the current through the 680 Ω resistor (in mA).



mA (Enter your answer as a number and press return)

Note that the circuit is now complete from the supply, via switch S1, through the 680 Ω resistor and the ammeter, and back to the supply.

- Set switch S1 to ON to complete the circuit and allow current to flow.

- Compare this with the value calculated earlier in the example using Ohm's Law.
- Move the leads so that the 2.2 k Ω resistor is in circuit as shown in Fig 1.2, and adjust the variable DC voltage control to give a current of 4 mA.

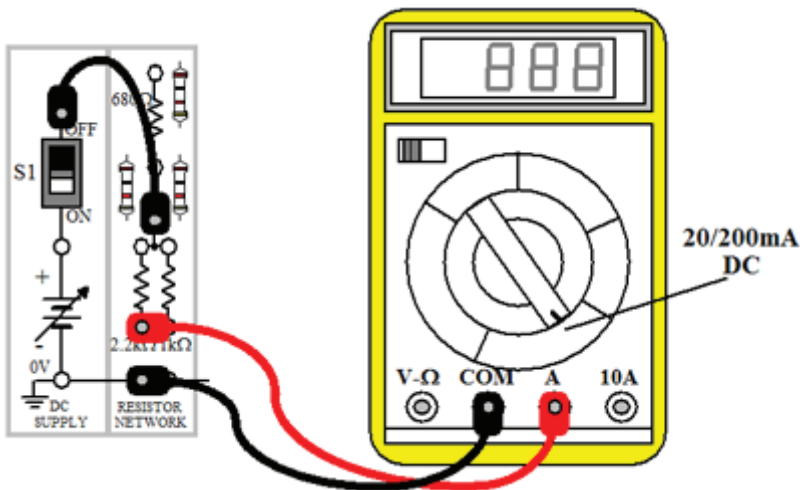


Figure 1.2

- Remove the multimeter from circuit and replace its connections with a shorting link to complete the circuit again.
- Select the 20 V DC range on the multimeter, move the positive (red) lead to the V- Ω socket and then re-connect the meter across the 2.2 k Ω resistor to measure the voltage across it.

5 Enter the voltage measured across the 2.2 k Ω resistor (in V).



8.91 V (Enter your answer as a number and press return)

- Compare this value with the calculated value entered in question 3.
- Disconnect the circuit, then before connecting the next circuit, set the variable DC voltage control for a supply voltage of 6 V (as measured across the variable voltage symbol in the DC Supply block), with switch S1 set to OFF.
- With the lamp still isolated from the supply, measure the resistance of the lamp using an appropriate ohmmeter range on the multimeter

6 Enter the measured value of the lamp resistance (cold) in Ω



10.3 Ω (Enter your answer as a number and press return)

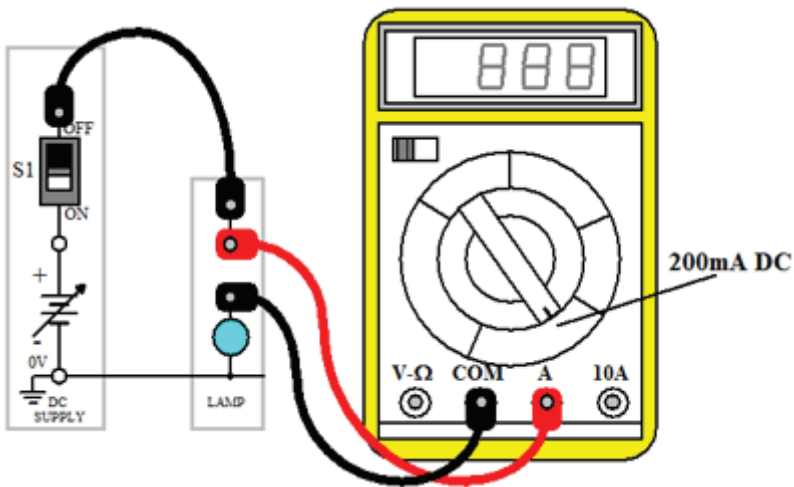


Figure 1.3

- Disconnect the digital multimeter from the circuit. Select the 200 mA DC range and move the positive (red) lead to the socket marked mA or A. Now reconnect the multimeter into the circuit as shown in Fig 1.3.
- Connect the DC Supply to the Lamp with a 2 mm connecting lead as shown in Fig 1.3 and set S1 to ON.
- Note the value of current flowing through the filament of the lamp.
- Divide the supply voltage (6 V) by the value of the current measured in the step above to find the resistance of the lamp.

7 Enter the calculated value of the lamp resistance (hot) in Ω .



112 Ω (Enter your answer as a number and press return)

Note that the resistance of the lamp has increased when the lamp temperature is raised to white hot to generate light.

8

For a given circuit and supply, if the resistance is increased, then the:



- ☐ voltage decreases.
- ☒ current decreases.
- ☐ current increases.
- ☐ current remains the same.

9

If the supply voltage to a circuit is increased, then the:



- ☐ resistance decreases.
- ☐ voltage across it decreases.
- ☒ voltage across it increases.
- ☐ resistance increases.

10

If the current flowing through a resistor is increased, then the:



- ☐ resistance decreases.
- ☐ voltage across it decreases.
- ☒ voltage across it increases.
- ☐ resistance increases.

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Investigating a Characteristic Graph for a Resistive Component

Lab Work – Investigating a Characteristic Graph for a Resistive Component

The characteristic of a component is obtained by comparing the voltage applied across a device with the current passing through it. This is usually displayed as a graph.

Use a digital multimeter to measure the voltage across, and the current through, three resistive components and draw a graph to compare the components.



Recommended Equipment

Items found in [320-00 Electronics Study Trainer](#):

- Patch board
- Component set
- Shorting links and connecting leads

Test equipment:

- 2 × Digital multimeters

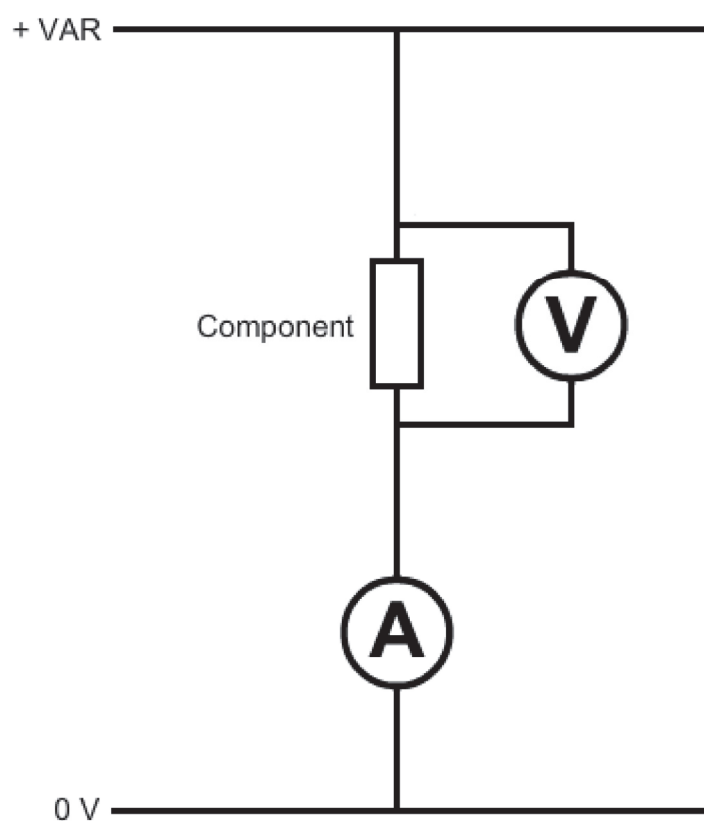
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Finding the Characteristic of a Component

Use the patch board to build this circuit initially using a $1\text{ k}\Omega$ resistor.

Adjust the variable supply to give approximately 0.5 V across the resistor.

Use the multimeters to read the corresponding values of voltage and current and record them in the table.



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Complete this table for the other voltages applied to the 1 k Ω resistor.

	1 k Ω Resistor	5 V lamp (LP)	Thermistor (TH)
Voltage in V	Current in mA	Current in mA	Current in mA
0	0	0	0
0.5	0.5	12.1	0.5
1.0	1.0	23.0	1.0
1.5	1.5	35.0	1.5
2.0	2.0	46.5	2.0
2.5	2.5	58.0	2.5
3.0	3.0	69.0	3.0
3.5	3.5	81.4	3.5
4.0	4.0	87.0	4.0

Now repeat this investigation for a 5 V lamp (LP) and a thermistor (TH).

a) Draw graphs of these results, clearly identifying which graph relates to which component.

(The graph may be completed electronically using a spreadsheet program or drawn on [graph paper](#))

b) Use the graph to calculate the resistance of the 1 k Ω resistor. Explain your calculation.

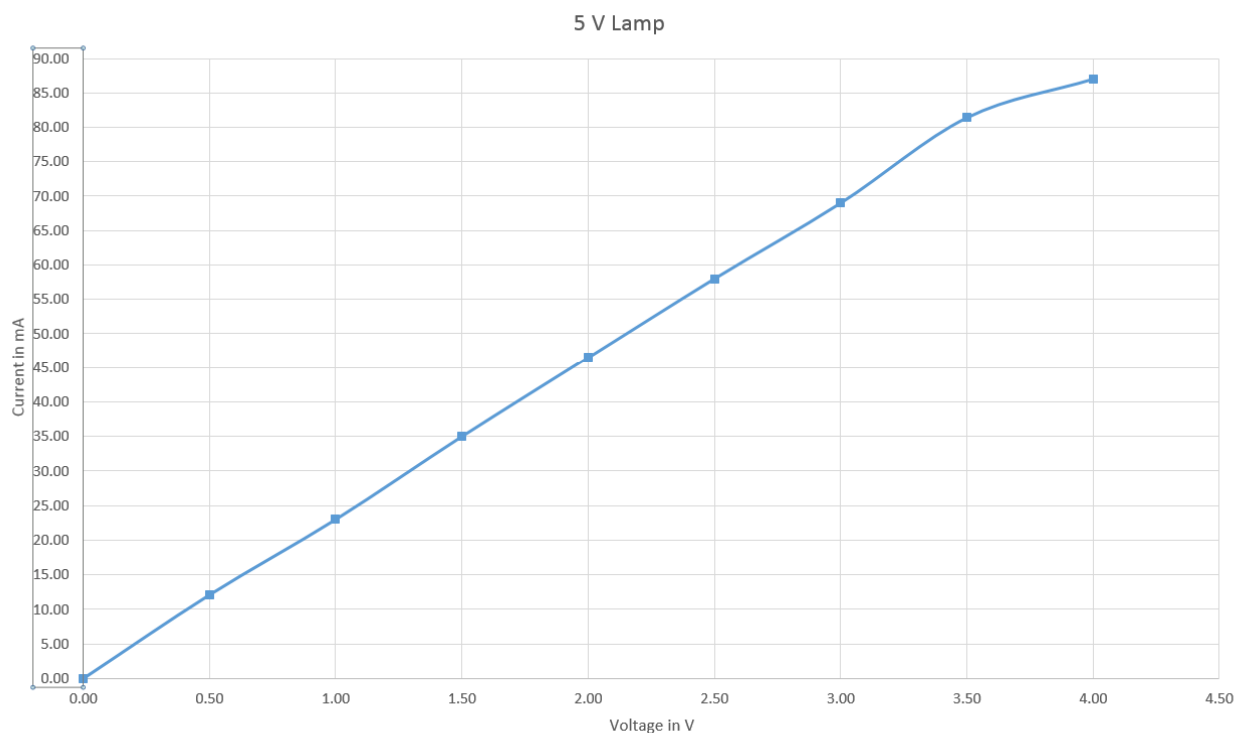
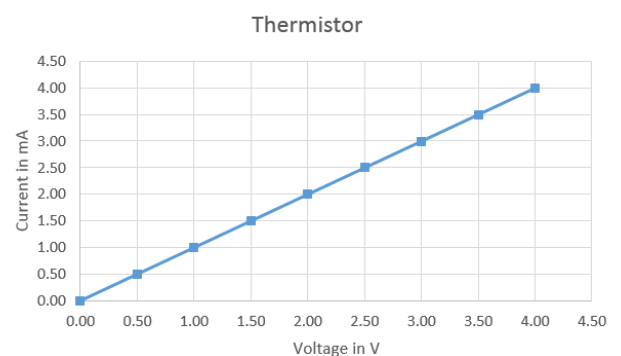
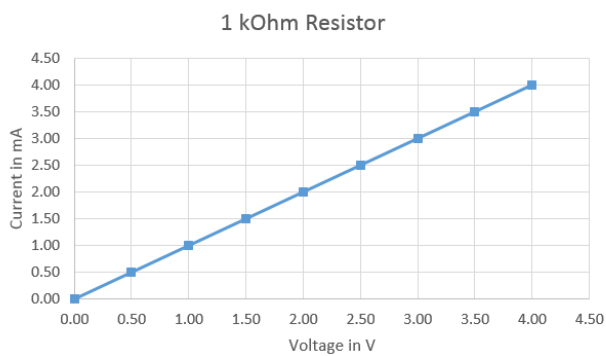
c) Comment on the shape of the graph for the lamp (LP). Calculate its minimum and maximum resistance.

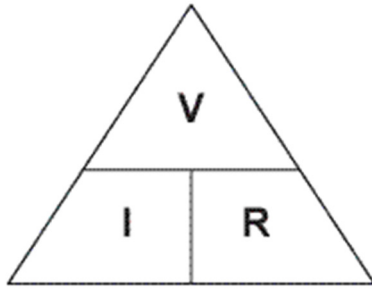
d) The thermistor (TH) is given the nominal value 4.7 k Ω . Is this justified by these results?

Resistance

a)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2		1 k Ω Resistor	5 V Lamp	Thermistor									
3	Voltage in V	Current in mA	Current in mA	Current in mA									
4	0.00	0.00	0.00	0.00									
5	0.50	0.50	12.10	0.50									
6	1.00	1.00	23.00	1.00									
7	1.50	1.50	35.00	1.50									
8	2.00	2.00	46.50	2.00									
9	2.50	2.50	58.00	2.50									
10	3.00	3.00	69.00	3.00									
11	3.50	3.50	81.40	3.50									
12	4.00	4.00	87.00	4.00									





b) 1 kΩ Resistor

$$R = \frac{V}{I}$$

$$\frac{3.0}{3.0} - \frac{1.5}{1.5} = \frac{1.5}{1.5 * 10^{-3}}$$

$$\frac{1.5}{1.5 * 10^{-3}} = 1000 = 1 \text{ k}\Omega$$

c) Comment on the shape of the graph for the lamp (LP). Calculate its minimum and maximum resistance.

The graph shows a rather uniform increase of current against voltage. We can see that the current is experiencing a steady rise as the voltage is increased, showing us its relative resistance.

c) 5 V Lamp

$$R = \frac{V}{I}$$

$$\text{Maximum } R = \frac{4.0}{87.0 * 10^{-3}}$$

$$\frac{4.0}{87.0 * 10^{-3}} = 45.97 = 46 \Omega$$

$$\text{Minimum } R = \frac{0.5}{12.1 * 10^{-3}}$$

$$\frac{0.5}{12.1 * 10^{-3}} = 41.32 = 41 \Omega$$

d) The thermistor (TH) is given the nominal value 4.7 k Ω. Is this justified by these results?

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Investigation of a Wheatstone Bridge

Recommended Equipment

- [D3000 - 9.10 Breadboard Platform Experiment Card](#)
- D3000 CS 9.10 Component Set
- 0.1" wire links
- Digital multimeter with ranges of 2 mA DC and 20 k Ω
- Connecting leads

Investigation of a Wheatstone Bridge

The D3000 CS 9.10 contains two unknown resistor values. In this activity we will use a Wheatstone bridge to determine these values. Using the components in the Component Set and on the D3000 9.0 Master Board you will construct the circuit shown in the schematic diagram of Fig 1.1.

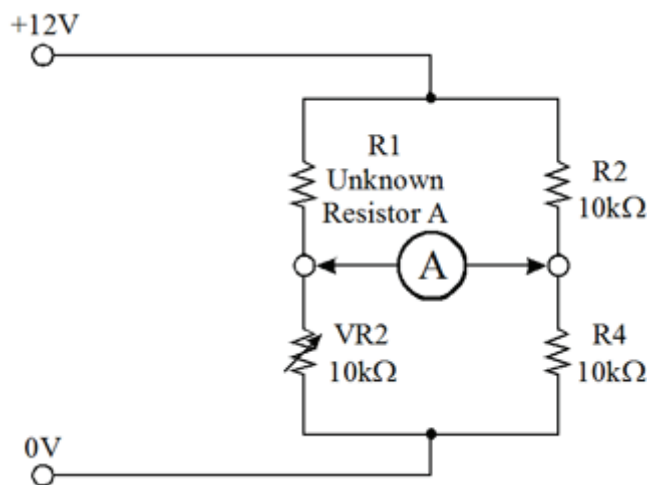


Figure 1.1

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- Construct the circuit shown in Fig 1.2 using the Component Set and appropriate wire links. Connect the digital multimeter into the circuit, set to its 2 mA DC range, as shown (ensure correct polarity of the meter). Note that the Accessory Kit is used to connect the multimeter and VR2 into the circuit.

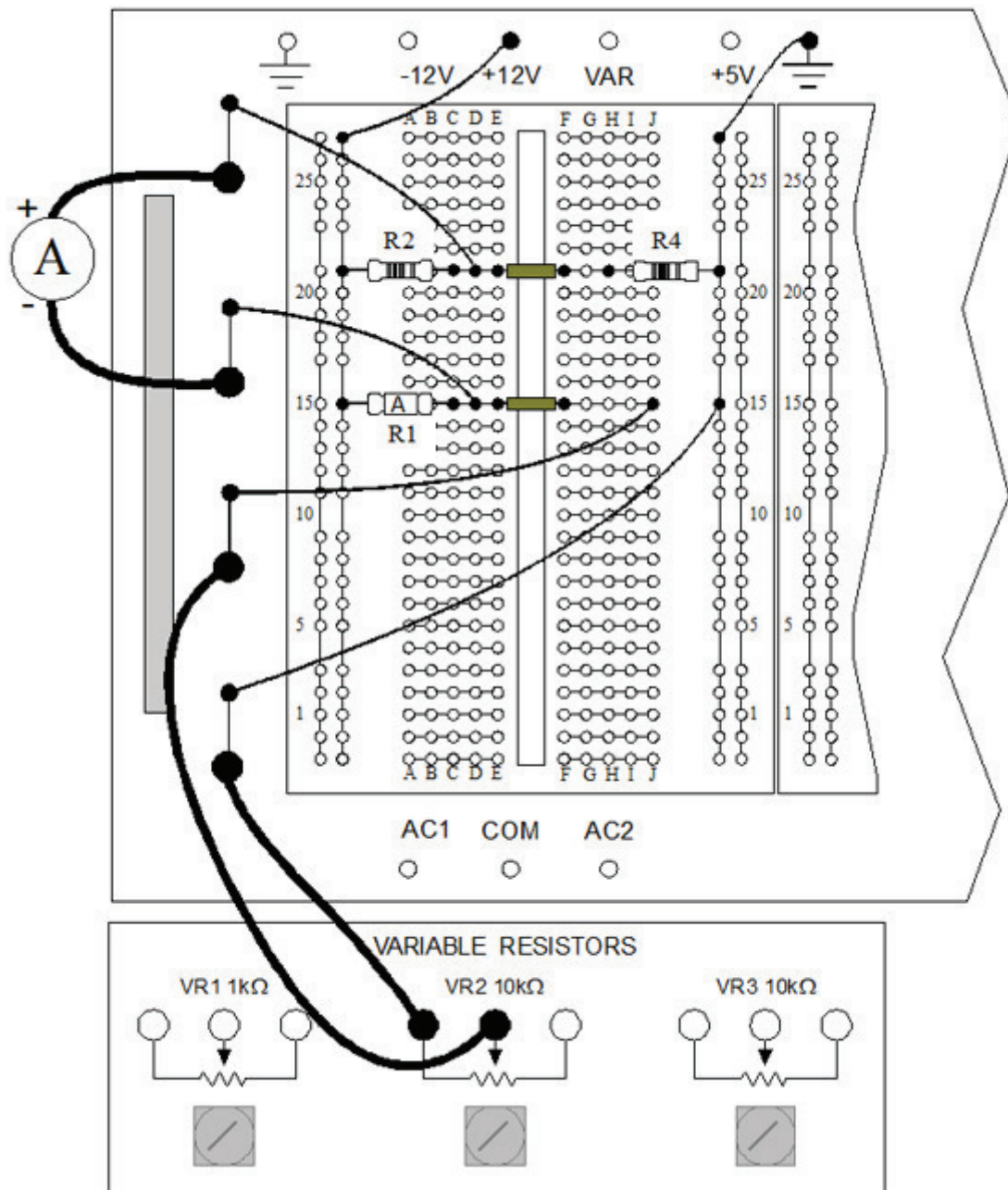


Figure 1.2

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- Ensure that VR2 is turned fully counter-clockwise, then switch ON the Power Supplies.
- Slowly turn the knob of VR2 clockwise until the ammeter reads zero, then turn OFF the Power Supplies.
- Disconnect VR2 and the multimeter from the circuit, then set the digital multimeter to read up to 20 k Ω . Place the multimeter across the two terminals of VR2 used in the circuit. Note the resistance value read on the multimeter below:
Resistance value =

As shown previously, because the values of R2 and R4 are equal, the value of unknown resistor A (R1) will be equal to the resistance value measured across the two terminals of VR2.

1 Enter the value of unknown resistor A (in k Ω).



k Ω (Enter your answer as a number and press return)

- Re-connect the circuit shown in Fig 1.2, but replace unknown resistor A with unknown resistor B. Ensure that the multimeter is set to its 2 mA DC range.
- Ensure that VR2 is turned fully counter-clockwise, then switch ON the Power Supplies.
- Slowly turn the knob of VR2 clockwise observing the ammeter reading as you do so.

You will notice that VR2 can be rotated through its whole range without the current through the ammeter reaching zero. This is because the value of unknown resistor B has a larger value than VR2.

To overcome this problem, we can change the ratio of R2 to R4, thereby making their ratio proportional to the ratio of unknown resistor B (R1) and VR2.

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Increasing the ratio between R2 and R4 would allow us to find larger values of unknown resistance, while decreasing the ratio between R2 and R4 would allow us to determine small values of unknown resistance more accurately.

You know that unknown resistor B is greater than 10 kΩ, because the current in the bridge could not be zeroed (balanced). Therefore, we must increase the ratio of R2 to R4. A ratio of ten will be used in this case, but greater ratios may be required at other times.

- Switch OFF the Power Supplies and change the value of R2 from 10 kΩ to 100 kΩ.

Note: It does not matter whether R2 or R4 has its value changed, as long as the ratio is 10. Therefore, R4 could have been changed to 1 kΩ.

- Ensure that VR2 is turned fully counter-clockwise, then switch ON the Power Supplies.
- Slowly turn the knob of VR2 clockwise until the ammeter reads zero, then turn OFF the Power Supplies.
- Disconnect VR2 and the multimeter from the circuit, then set the digital multimeter to read up to 20 kΩ. Place the multimeter across the two terminals of VR2 used in the circuit. Note the resistance value read on the multimeter below:
Resistance value =

Because the values of R2 and R4 are not equal, the formula $R1 = R2/R4 \times R3$ will be required to calculate the value of unknown resistor B (R1). Calculate the value of unknown resistor B and note its value:

Unknown Resistor B =

2

Enter the value of unknown resistor B (in kΩ).



kΩ (Enter your answer as a number and press return)

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3

Which of the following statements is not true?



- ☐ When R_2 equals R_4 , R_1 equals R_2 at balance.
- ☐ Increasing the ratio of R_2 to R_4 allows large unknown resistance values to be measured.
- ☐ To increase the ratio between R_2 and R_4 , you can decrease the value of R_4 .
- ☒ To accurately measure a small unknown resistance, you can increase the value of R_4 .

- Ensure that the Power Supplies are switched OFF, and remove the components, connecting leads, jump links and digital multimeter from the circuit. Return the components, leads and links to their storage cases.

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Exercise 11.1 Resistance Measurement Using a Wheatstone Bridge

Unknown Resistor	R24	R25	R26 at balance	Resistance
Ra	12 k Ω	12 k Ω		Ra =
Rb	12 k Ω	12 k Ω		Rb =
Rc	12 k Ω	12 k Ω		Rc =

Table 11.1

Ra = k Ω

Rb = k Ω

Rc = k Ω

Ra = 1.75 k Ω

Rb = 7.99 k Ω

Rc = 5.46 k Ω

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Capacitor Discharge Curve

Lab Work – Capacitor Discharge Curve

As a capacitor discharges through a resistance, the voltage across the capacitor will fall. The time constant for the circuit is given by this equation:

$$\tau = CR$$

where:

τ is the time constant in seconds

C is the capacitance of the capacitor in farads

R is the resistance in ohms.



Discharge a capacitor through a large resistance and plot the capacitor voltage against time.

Use your graph to confirm the time constant for the circuit.

Recommended Equipment

Items found in [320-00 Electronics Study Trainer](#):

- Patch board
- Component set
- Shorting links and connecting leads

Test equipment:

- Digital multimeter
- Stopwatch

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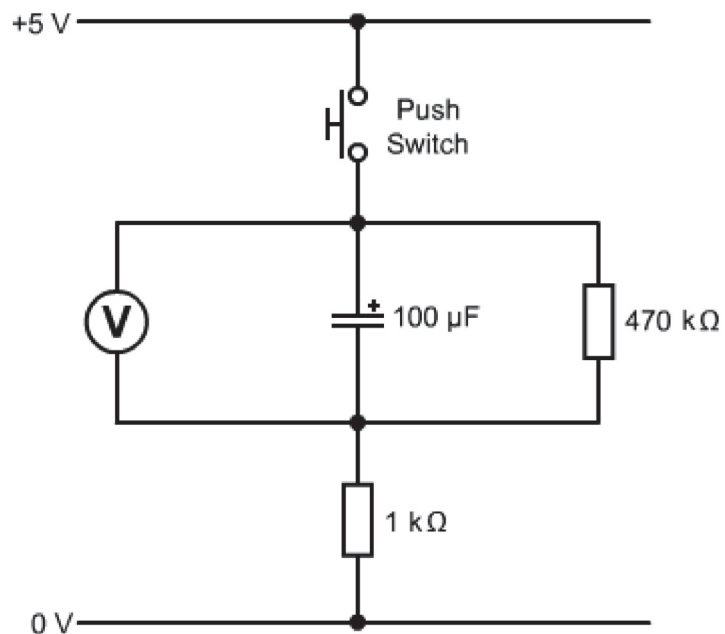
Procedure

Build this circuit using the Electronics Study Trainer.

With the press switch closed, the capacitor will charge up. Charge up the capacitor by closing the switch for a few seconds. Note the initial voltage.

Complete the table with voltage readings taken every 10 seconds from when the press switch is released.

Time in s	Voltage in V
0	4.99
10	4.02
20	3.26
30	2.36
40	2.12
50	1.72
60	1.39
70	1.13
80	0.91
90	0.74
100	0.60



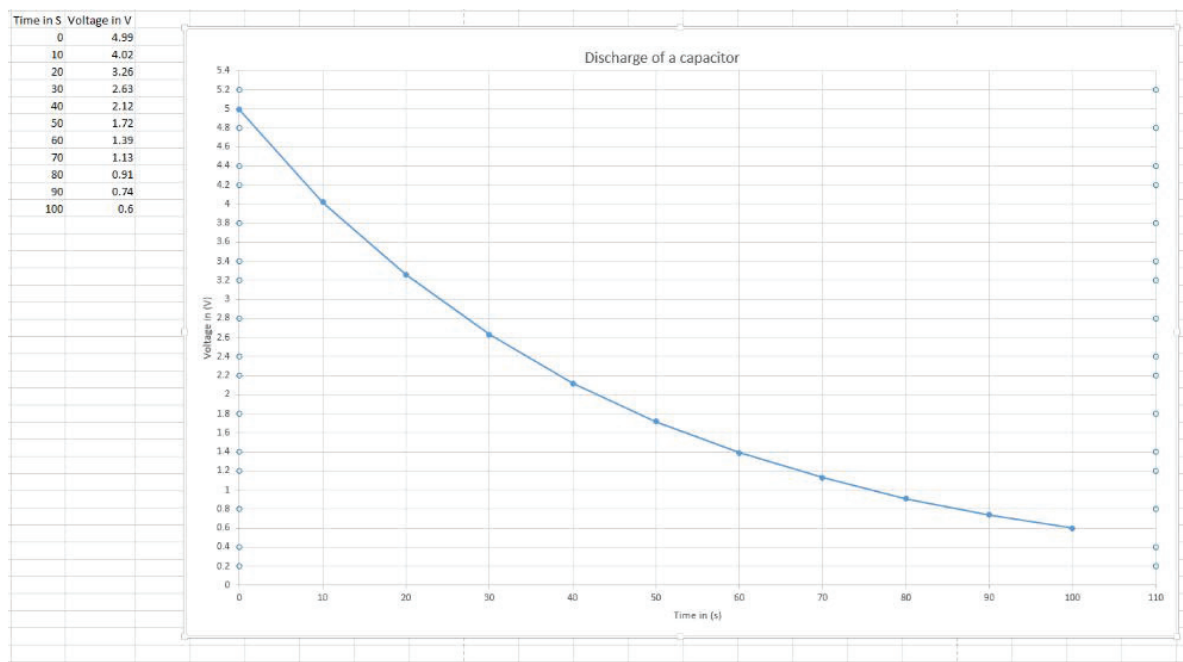
Plot your results on a graph of capacitor voltage against time.

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- a) What is the purpose of the 1 k Ω resistor in series with the capacitor?
- b) The voltage should drop to 37 % of the initial voltage in one time constant. Calculate 37 % of the initial voltage.
- c) Use your graph to find the time taken for the voltage to drop to 37 % of the initial voltage.
- d) Use the time constant equation to calculate the resistance of the resistor the capacitor has discharged through. The capacitance of the capacitor is 100×10^{-6} F.
- e) How does the calculated value of resistance compare with the stated value of 470 k Ω ? Explain any discrepancy.

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Capacitance



A) The $1k\Omega$ resistor is there to limit the current used to charge the resistor and to minimise the noise throughout the circuit.

B) 37% of initial voltage

$$37\% = (4.99/100) * 37$$

$$37\% = 1.85 \text{ V (2 d.p)}$$

C) Time taken to reach 37% of initial voltage

$$1.85 \text{ V} = \underline{47.5 \text{ seconds}}$$

D) Find the resistance of the resistor the capacitor discharged through.

$$t = CR$$

$$t = (100 \times 10^{-6}) R$$

$$47.5 = 100 \times 10^{-6} R$$

$$R = 47.5 / 100 \times 10^{-6}$$

$$R = 475000$$

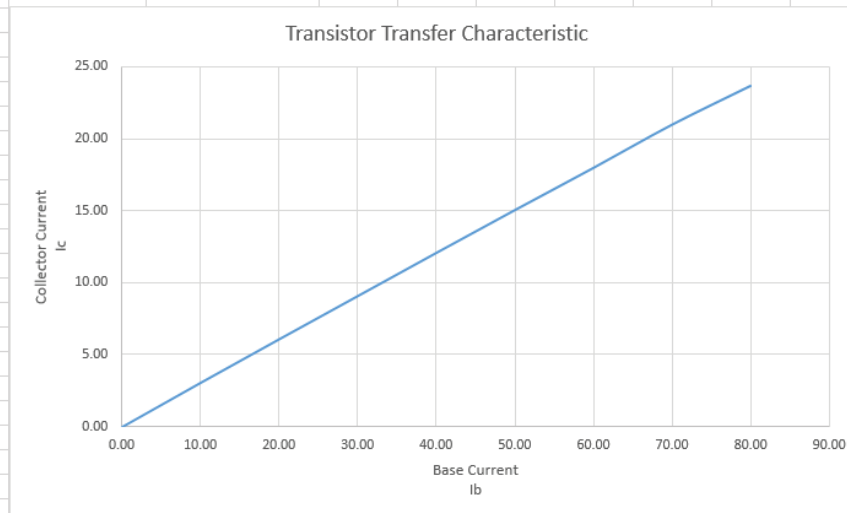
$$R = 475k \text{ Ohms}$$

E) How does the calculated value of resistance compare with the stated value of $470 \text{ k}\Omega$? Explain any discrepancy.

The value I calculated is 5000 ohms greater than the value of resistance stated. I believe this is because the method used to define the time taken for the voltage to reach 37% of the initial value was not very accurate, and was off by a few milliseconds, creating an area for error.

Bipolar Transistor Characteristics

Base Current I_b	Collector Current I_c
0.00	0.00
10.00	3.07
20.00	6.10
30.00	9.10
40.00	12.10
50.00	15.07
60.00	18.00
70.00	21.00
80.00	23.70



- a) Which region of the transfer characteristic is shown by your graph?

My graph shows the active region of the transfer characteristics for the transistor, as the current is still being converted by the transistor. The saturated region is not shown on the graph.

- b) Find the change in collector current that occurred when the base current was increased from 0 μA to 80 μA , and use this to calculate the current gain of the transistor.

$$\beta = \frac{I_c}{I_b}$$

$$\beta = \frac{23.7}{80} - \frac{0}{0}$$

$$\beta = \frac{23.7}{80} = 0.30 \text{ (2dp)}$$

The AC Performance of a Non-Inverting Amplifier

Recommended Equipment

- [D3000 - 9.12 Operational Amplifier Experiment Card](#)
- Dual trace Oscilloscope
- Signal (Function) Generator
- Shorting links and connecting leads

The AC Performance of a Non-Inverting Amplifier

Fig 1.1 is the circuit that will be investigated in this activity. Each oscilloscope lead should be grounded. The signal generator should be connected via the BNC connector on the base unit.

The 100 k Ω resistor connected from the +ve input to ground does not affect the performance of the amplifier. It is there to prevent the amplifier drifting when there is no input to the +ve input.

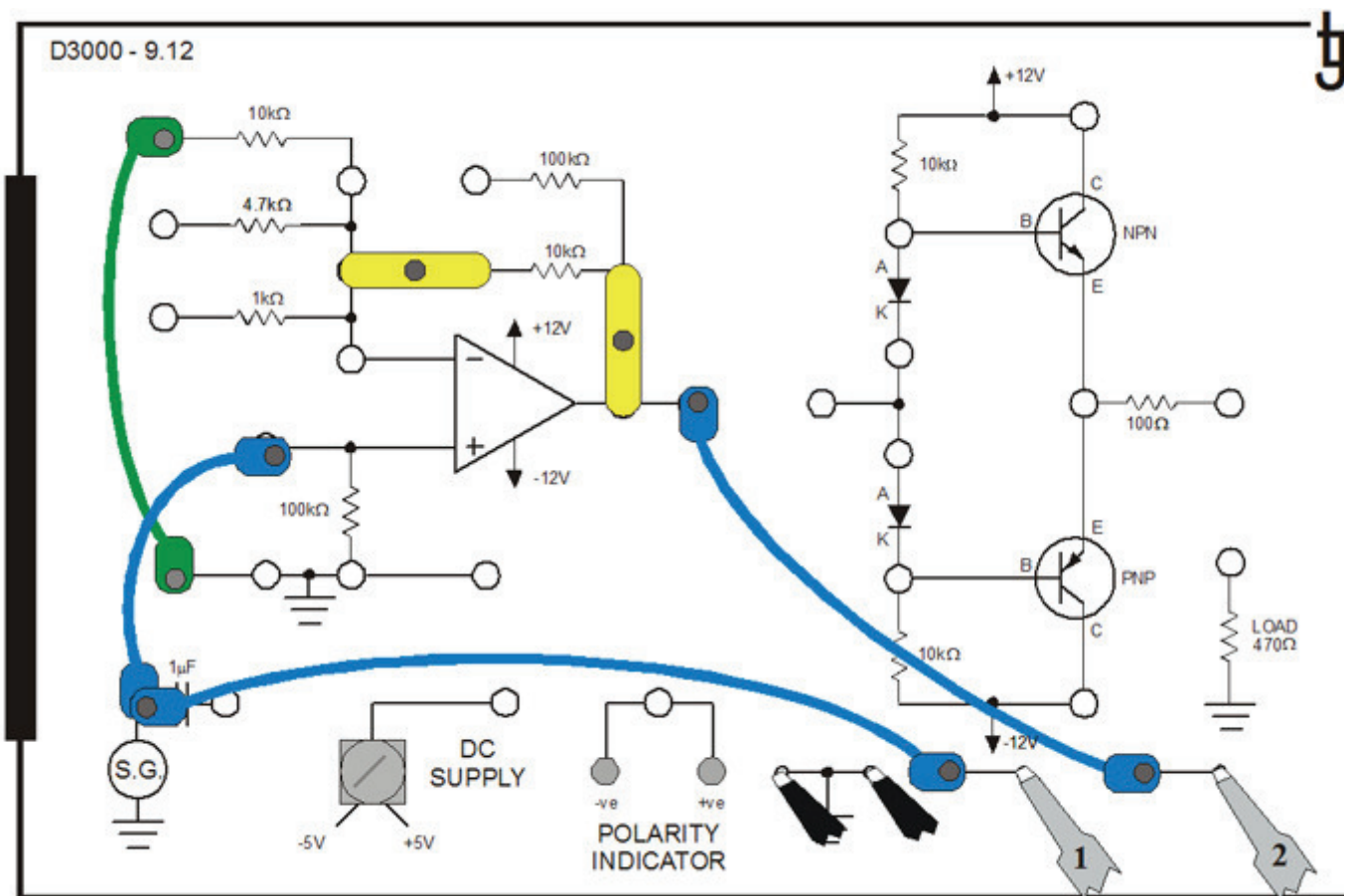


Figure 1.1

- Connect the links and leads as shown in Fig 1.1. Initially set both the oscilloscope channels CH.1 and CH.2 to 2 Volts/div and the time base to 0.5 ms/div. Switch ON the power and, with the help of oscilloscope CH.1, set the signal generator to give a 1 kHz sine wave with 4 volt p-p (peak to peak) amplitude. The oscilloscope should be triggered from CH.1.

1

What do you expect to see on CH.2?



- ☒ An 8 volt p-p sine wave in phase with CH.1.
- ☐ A 4 volt p-p sine wave in phase with CH.1.
- ☐ An 8 volt p-p sine wave inverted (phase shifted by -180°).
- ☐ A 4 volt p-p sine wave inverted (phase shifted by -180°).

Since R_i equals R_f , the amplitude gain is 2, that is the peak to peak output is twice the peak to peak input. The positive sign in the gain equation shows that the output is not inverted, that is it is in phase with the input.

- Measure the input and output p-p voltages and fill up the appropriate row of Table 1.1. If the output is in phase with the input, enter 0° in the last column. Enter -180° if the output is inverted.

R_i k Ω	R_f k Ω	Calc Gain	Input V _{p-p}	Output V _{p-p}	Measured Gain	Phase Change
10	10	2	4	8	2	0
10	100	11	0.70	8	11	0
1	100	101	0.80	8	100	0

Table 1.1

- Change the feedback resistor R_f to 100 k Ω by moving the shorting link up to the top set of holes.
- Adjust the input amplitude until the amplifier output (CH.2) is again 8 V p-p. The CH.1 gain settings on the oscilloscope will require to be changed to allow the input amplitude to be measured.
- Measure the input voltage and the phase shift relative to the input. Enter your results in Table 1.1.
- Change R_i to 1 k Ω by moving the connection from the oscillator then repeat the above steps and complete the table.

2

What do you conclude from this experiment?



- ☐ The gain changes by the ratio of $1 + R_i/R_f$ and the output is inverted relative to the input.
- ☐ The gain changes by the ratio of $1 + R_f/R_i$ and the output is inverted relative to the input.
- ☒ The gain changes by the ratio of $1 + R_f/R_i$ and the phase is not inverted relative to the input.
- ☐ The gain and phase θ both change with the ratio of $1 + R_f/R_i$.

3

Which of the following statements is true?



- ☐ The phase shift increases as gain is increased.

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- ☒ The phase shift does not change with gain.
- ☐ The phase shift decreases as gain is increased.

- Switch OFF the module supply, signal generator and oscilloscope. Remove all links and leads and return them to their storage locations.

The AC Performance of an Inverting Amplifier

Recommended Equipment

- [D3000 - 9.12 Operational Amplifier Experiment Card](#)
- Dual trace Oscilloscope
- Signal (Function) Generator
- Shorting links and connecting leads

Fig 1.1 is the circuit that will be investigated in this activity. The signal generator should be connected via the BNC connector on the base unit. The signal generator output appears on the terminal marked SG at the bottom left of the circuit board.

- Connect the links and leads as shown in Fig 1.1. Set both the oscilloscope channels CH.1 and CH.2 to 2v/div and the time base to 0.5 ms/div. Switch ON the power and, with the help of oscilloscope CH.1, set the signal generator to give a 1 kHz sine wave with 8 volts p-p (peak to peak) amplitude. The oscilloscope should be triggered from CH.1.

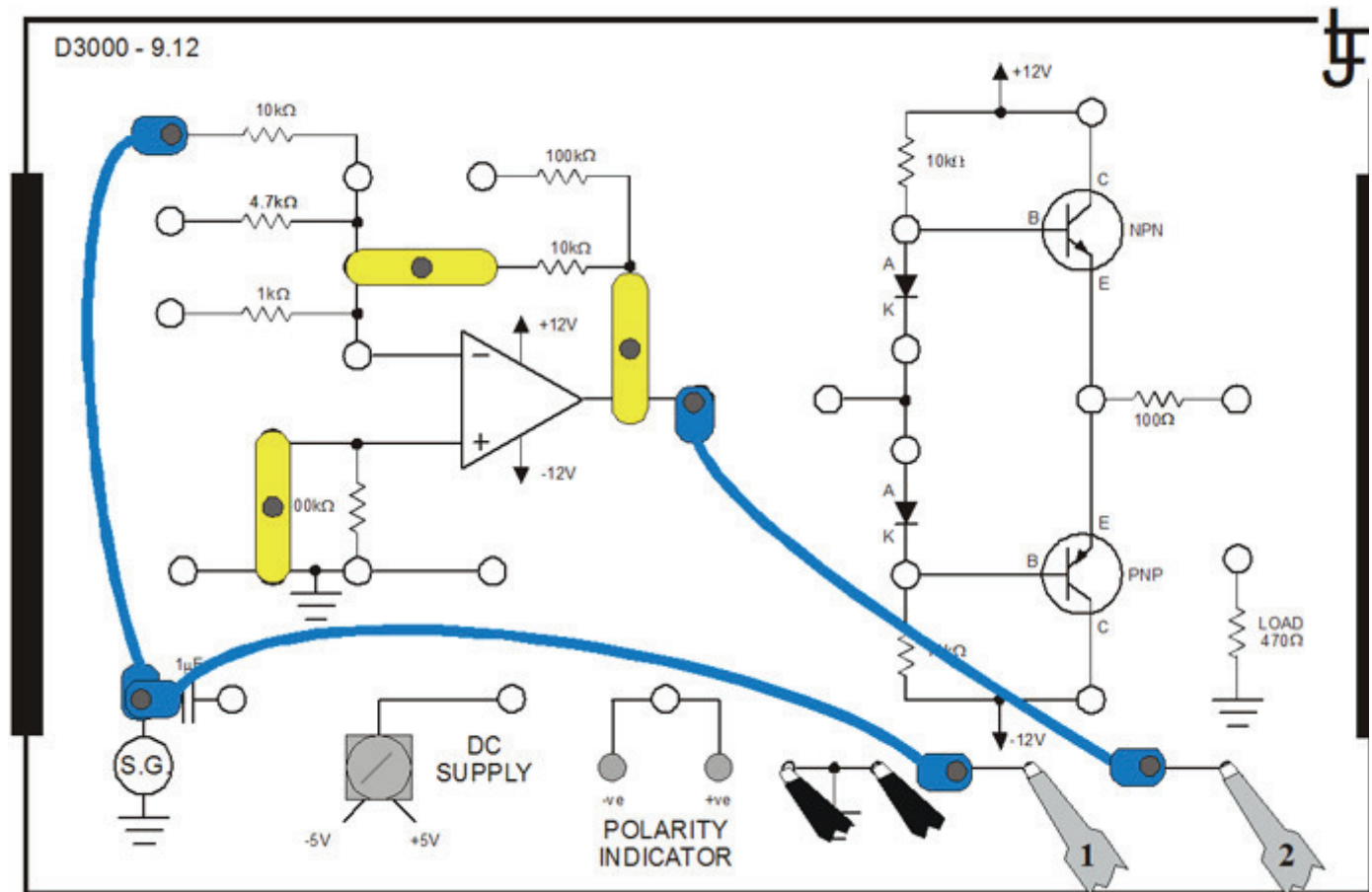


Figure 1.1

1 What do you expect to see on CH.2?



- ☐ An 8 volt p-p sine wave in phase with CH.1.
- ☐ A 0.8 volt p-p sine wave in phase with CH.1.
- ☒ An 8 volt p-p sine wave inverted (phase shifted by -180°).
- ☐ A 0.8 volt p-p sine wave inverted (phase shifted by -180°).

Since R_i equals R_f , the gain G is 1. That is, the peak to peak output equals the peak to peak input. The negative sign in the equation inverts the output which is the same as adding a phase shift of -180° .

- R_i and R_f are set as in the first row of Table 1.1. Calculate the expected gain then measure the input and output p-p voltages. Fill in the first row of Table 1.1.

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R_i k Ω	R_f k Ω	Calc Gain	Input V _{p-p}	Output V _{p-p}	Measured Gain	Phase Change θ
10	10	1	8	8	1	-180
10	100	10	0.77	8	10.4	-180
1	100	100	0.079	8	101.3	-180

Table 1.1

- Change the feedback resistor R_f to 100 k Ω by moving the shorting link up to the top set of holes.
- Adjust the input amplitude until the amplifier output (CH.2) is again 8 V p-p. The CH.1 gain settings on the oscilloscope will require to be changed so that the amplitude of the input signal can be measured.
- Measure the input voltage and the output phase relative to the input. Enter your results in Table 1.1.
- Change R_i to 1 k Ω by moving the connection from the signal generator then repeat the steps.

2 What do you conclude from this experiment?



- ☐ The gain changes by the ratio of R_i/R_f and the output is inverted relative to the input.
- ☒ The gain changes by the ratio of R_f/R_i and the output is inverted relative to the input.
- ☐ The gain changes by the ratio of R_f/R_i and the output is not inverted.
- ☐ The gain and phase θ both change with the ratio of R_f/R_i .

3 Which of the following statements is true?



- ☐ The phase shift increases as gain is increased.
- ☒ The phase shift does not change with gain.
- ☐ The phase shift decreases as gain is increased.

- Switch OFF the module supply, signal generator and oscilloscope. Remove all links and leads and return them to their storage locations.