

Lab 10

RC Circuits

Learning Goals:

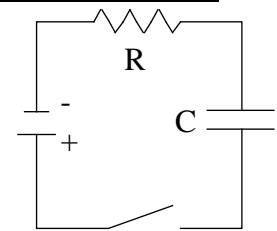
- to measure the voltage across a capacitor as it is charged and then discharged through a resistor that is in series with the capacitor
- to calculate the capacitance of the capacitor based on data and compare it to the printed value on the capacitor.
- to construct a voltage rectifier and compare its input and output wave characteristics

Apparatus:

Qty	Items	Instrumental Error	Instrumental Resolution
1	GLX, Data Studio Software	± 0.1%	0.001 volts, 0.001 sec
1	Voltage Sensor (red +, black -)	± 0.020 volts	± 0.005 volts
1	AC/DC Electronics Laboratory		
2	Banana Plug Patch Cord		
1	Resistors: 10kΩ, 100kΩ	See color code	
1	Capacitors: 10μf, 470μf	See capacitor label	
1	Oscilloscope	± 0.005 volts	± 0.001 volts
4	Diodes		
1	410 ohm, 680 ohm resistors, 2.2 μf and 330 μf capacitors		

Theory:

Capacitors



A capacitor is a circuit element which can store, or release charge. You have seen a simple example of a capacitor in the E-field mapping lab, in which two oppositely charged “plates” separated by a distance created a uniform electric field between them. In a circuit, however, capacitors are essentially a “gap” in the circuit. When the two plates are neutral (uncharged) and connected to a battery, the capacitor plates draw charges from the battery very quickly, causing a current in the circuit for a very short duration. Depending on the *capacitance*, **C** in Farads, of the capacitor, charges will move onto both plates until the capacitor is full of excess charges (negative charges on one plate, positive charges on the other). This separation of charges creates an electric field between the plates, which results in a measurable voltage difference. The charge stored on the capacitor is found by measuring the voltage across, and the capacitance of, the capacitor and multiplying them together:

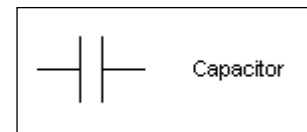
$$(1) \quad Q = CV$$

where

Q ≡ “charge on capacitor” [Coulombs]

C ≡ “capacitance” [Farads]

V ≡ “voltage across capacitor” [Volts]



Resistor-Capacitor (RC) Circuits

When a DC voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up decreases as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates. But as charge accumulates on the plates, the voltage

source must “do more work” to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the plates at any time is given by: $q = q_0(1 - e^{-t/\tau})$ where q_0 is the maximum charge on the plates and τ is the capacitive time constant in seconds ($\tau = RC$, where R is resistance in ohms and C is capacitance in farads). NOTE: The stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual value. Taking the extreme limits, notice that when $t = 0$, $q = 0$ which means there is not any charge on the plates initially; also notice that when t goes to infinity, q goes to q_0 which means it takes an infinite amount of time to completely charge the capacitor.

The time it takes to charge the capacitor to half full is called the half-life and is related to the capacitive time constant in the following way:

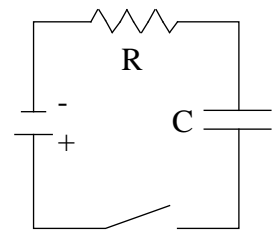
$$t_{1/2} = RC \ln 2 \text{ and } t_{1/2} = \tau \ln 2 = \tau (0.693)$$

The time it takes to charge the capacitor to 63.2% of full charge is called the time constant τ .

In this activity the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: $q = CV$.

When a resistor is connected across a charged capacitor, the rate at which the capacitor discharges decreases as time passes. At first, the capacitor is easy to discharge because there is much charge on the plates. But as charge leaves the plates, its function as a voltage source decreases. As a result, the capacitor discharges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully discharged.

The charge on the plates at any time is given by: $q = q_0(e^{-t/\tau})$ where q_0 is the maximum charge on the plates and τ is the capacitive time constant in seconds ($\tau = RC$, where R is resistance in ohms and C is capacitance in farads). NOTE: The stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual value. Taking the extreme limits, notice that when $t = 0$, $q = q_0$ which means there is full charge on the plates initially. Also notice that when t goes to infinity, q goes to zero which means it takes an infinite amount of time to completely discharge the capacitor.



The time it takes to discharge the capacitor to half full is called the half-life and is related to the capacitive time constant in the following way: $t_{1/2} = RC \ln 2$ and $t_{1/2} = \tau \ln 2$. The time it takes to discharge the capacitor to 36.8% of full charge is called the time constant τ .

In this activity the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: $q = CV$

The voltage across a *charging* capacitor in an RC circuit as a function of time is:

$$(2) \quad V_c = V_{\max} (1 - e^{-(t/\tau)})$$

where

$V_c \equiv$ “charge on capacitor as a function of time (dependent variable)”

$V_{\max} \equiv$ “maximum charge on a charging capacitor”

$t \equiv$ “time (independent variable)”

$\tau \equiv$ “RC time constant, or time to charge capacitor to 63.2 % of maximum” = **RC**

R \equiv “resistance”

C \equiv “capacitance”

“e” is Euler’s number ≈ 2.718 .

Suppose this charged capacitor is then connected alone with the resistor. The charged capacitor will discharge all its charge until it is completely neutral again. The voltage across a *discharging* capacitor with respect to time becomes:

$$(3) \quad V_d = V_{\max} (e^{-(t/\tau)})$$

where

$V_d \equiv$ “charge on capacitor as a function of time (dependent variable)”

$V_{\max} \equiv$ “maximum charge on a discharging capacitor”

$t \equiv$ “time (independent variable)”

$\tau \equiv$ “*RC time constant*, or time to discharge capacitor to 36.8 % of maximum” = **RC**

R \equiv “resistance”

C \equiv “capacitance”

$$(4) \quad t_{1/2} = \tau \ln 2$$

where

$t_{1/2} \equiv$ “*half life*, or time to charge (or discharge) capacitor to 50% of maximum”

$\tau \equiv$ “*RC time constant*” = **RC**

The “ln” in equation (4) is the natural log.

Prelab:

- #1 On the axes below mark the horizontal in seconds from 0.0 to 50.0 and the vertical in volts from 0.0 to 16.0. Entitle the graph,
“The accumulation of Charge on a Capacitor as Evidenced by the Voltage across it in time.”



- #2 On the axes above, plot the following points (0.0 sec, 0.0 volts), (5.0 sec, 8.0 volts), (10.0 sec, 12.0 volts), (15.0 sec, 14.0 volts), (20.0 sec, 15.0 volts), (25.0 sec, 15.5 volts), (50.0 sec, 15.98 volts). Connect these points with a smooth curve.

See circuit below: One wire of this capacitor is connected to a power supply with a constant voltage of 16.0 volts. The other wire of the capacitor is also connected to a resistor and the resistor is connected to the power supply. When the switch is closed, charge flows from the power supply, through the resistor and into the capacitor. The half-time to charge is 5.0 seconds and the capacitor is effectively fully charged in ten half-times. The time constant for this charge is 7.2 seconds. Mark these two times on both axes above.

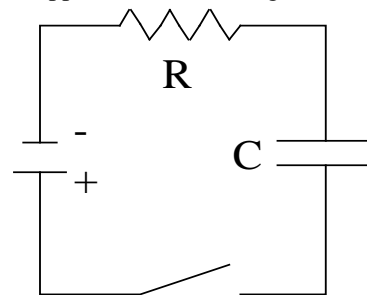
- #3 On the axes below mark the horizontal in seconds from 0.0 to 50.0 and the vertical in volts from 0.0 to 16.0. Entitle the graph,
“The removal of Charge on a Capacitor as Evidenced by the Voltage across it in time.”



- #4 On the axes above, plot the following points (0.0 sec, 16.0 volts), (5.0 sec, 8.0 volts), (10.0 sec, 4.0 volts), (15.0 sec, 2.0 volts), (20.0 sec, 1.0 volts), (25.0 sec, 0.5 volts), (50.0 sec, 0.02 volts). Connect these points with a smooth curve.

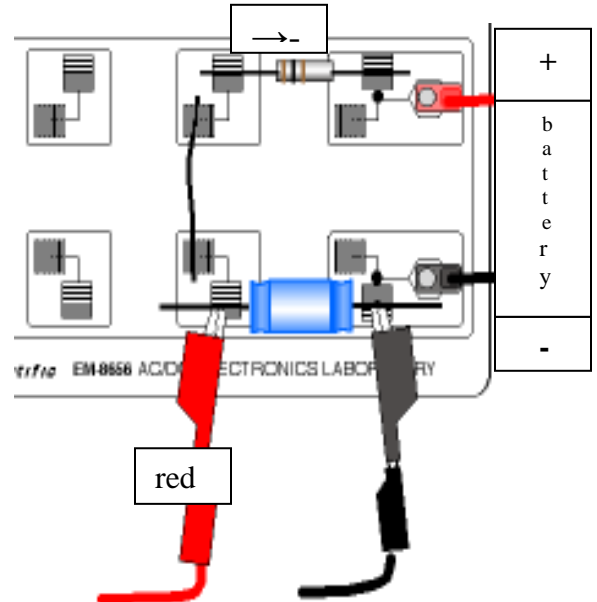
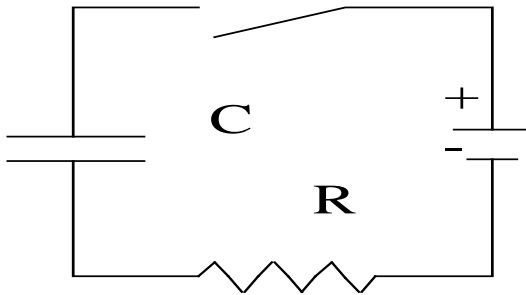
See circuit below: One wire of this capacitor is connected to a resistor and the resistor to a wire and then back to the other wire of the capacitor. When the switch is closed, charge stored in the capacitor flows from one wire of the capacitor, through the resistor and into the other wire of the capacitor. The half-time to discharge is 5.0 seconds and the capacitor is effectively fully discharged in ten half-times. The time constant for this discharge is 7.2 seconds. Mark these two times on both axes above.

- #5 In the circuit at the left, C is the capacitor and the power supply is at the left. When the switch is closed, negative charge flows clockwise from the power supply through the resistor and collects on the upper conductor of the capacitor. For each negative charge collected on the upper conductor, a negative charge flows from the lower connector clockwise back into the power supply. When the capacitor is fully charged, the electric field between the capacitor conductors is equal to the electric field between the conductors of the power supply. To draw this situation of full charge, draw ten negative signs on the upper conductor of both the power supply and the capacitor; draw ten positive charges on the lower conductor of both the power supply and the capacitor

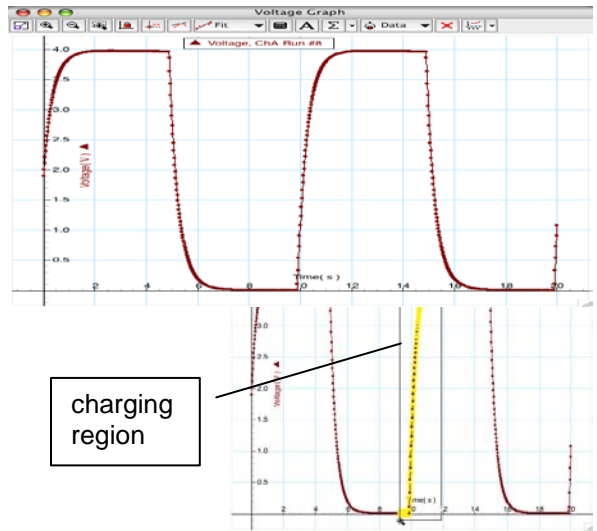


Procedure Charging a Capacitor From 1.5 volt Battery:

1. Open Data Studio and select “create an experiment” and set the resolution to four significant figures for the voltage and 5,000 samples per second for the time. Select a graph display to monitor the charging and discharging of the capacitor through the resistor.
2. Attach the voltage sensor to the GLX and connect the GLX to the computer. Turn on the GLX with the voltage sensor attached across the capacitor.



3. Set up the circuit shown in the illustration. Place a 10k-ohm resistor (brown, black, orange) in the pair of spring clips nearest to the top banana jack at the lower right corner of the AC/DC Electronics Laboratory board.
4. Place a 470 microfarad (μF) capacitor in the pair of spring clips nearest the bottom banana jack on the board. Connect a wire lead between spring clips at the left end of the resistor and the capacitor.
5. Put alligator clips on the voltage sensor leads and connect the clips at each end of the capacitor
6. Connect **one** 1.5 volt dry cell in series with the push button switch and the resistor and capacitor.
7. In *DataStudio*, simultaneously click ‘Start’ and push button board to begin recording data. Watch the Graph display of voltage versus time.
8. Rescale the Graph display if needed. Expand a region of the Graph display. Use the ‘Zoom Select’ tool in *DataStudio* to click-and-draw a rectangle over a region of the plot of Voltage versus Time that shows the voltage rising from zero volts to the maximum volts. Use the built in analysis tool in the Graph display to find the time to “half max.”
9. Click the ‘Smart Tool’. Move the cursor to the point on the plot where the voltage begins to rise. Drag the corner of the ‘Smart Tool’ to the point where the voltage is one half of the final voltage. The time to ‘half-max’ is the “x”- coordinate.
10. Record the time to ‘half-max’ in the data table in the notebook. Use $t_{1/2} = (RC)$ (0.693) to calculate the capacitance (C) of the capacitor. $C = t_{1/2}/0.693R$
11. Record in the data table the time when the voltage is 63.2% of the final voltage. Use $\tau = (RC)$ to calculate the capacitance (C) of the capacitor. $C = \tau/R$



Procedure Charging a Capacitor From 3.0 volt Battery:

12. Repeat procedures 3-11 using **two** 1.5 volt dry cells in series (i.e., 3.0 volts) with a 100k ohm resistor (brown, black, yellow) and a 10 microfarad (μF) capacitor.
13. Record the observations in the data table
14. Note the units in the data table and adhere to the rules of significant figures.

Data Charging a Capacitor From 1.5 volt and 3.0 volt Batteries (record in notebook)

Resistor value	(10k \pm) Ohms	Resistor value	(100k \pm) Ohms
Capacitor value	(470 \pm) μ Farads	Capacitor value	(10 \pm) μ Farads
EMF of 1.5 v battery	(\pm) Volts	EMF of 3 v batteries	(\pm) Volts
Half time to charge $t_{1/2}$	Sec	Half time to charge $t_{1/2}$	Sec
Calculated value of C	μ Farads	Calculated value of C	μ Farads
Per cent difference		Per cent difference	
Time constant to charge τ	Sec	Time constant to charge τ	sec
Calculated value of C	μ Farads	Calculated value of C	μ Farads
Per cent difference		Per cent difference	

Procedure Discharging a Capacitor From 1.5 volts

15. Place a 10k-ohm resistor (brown, black, orange) in the pair of spring clips nearest to the top banana jack at the lower right corner of the AC/DC Electronics Laboratory board. Place a 470 microfarad (μF) capacitor in the pair of spring clips nearest the bottom banana jack on the board. Repeat procedures #3-#5 but charge the capacitor by connecting **one** 1.5 volt dry cell directly to the capacitor.
16. Disconnect the **one** 1.5 volt dry cell and connect the push button in series with the resistor and the capacitor.
17. Start Data Studio and then hold the push button down until the capacitor appears to be completely discharged.
18. Repeat procedures #8- #10 but locate the time when the voltage decreases to one-half its initial value. Record the time value in the data table. Use $t_{1/2} = (RC) (0.693)$ to calculate the capacitance (C) of the capacitor. $C = t_{1/2}/0.693R$ Record this value in the data table.
19. Record in the data the time when the voltage across the capacitor is 36.8% of its initial value. section. Use $\tau = (RC)$ to calculate the capacitance (C) of the capacitor. $C = \tau/R$

Procedure Discharging a Capacitor From 3.0 volts

20. Repeat procedures #15-#19 using **two** 1.5 volt dry cells in series (i.e., 3.0 volts) with a 100k ohm resistor (brown, black, brown) and a 10 microfarad (μF) capacitor.
21. Record the observations in the data table with units and significant figures.

Data Discharging a Capacitor From 1.5 volts and 3.0 volts. (record in notebook)

Resistor value	(10k ±) Ohms	Resistor value	(100k ±) Ohms
Capacitor value	(470 ±) μ Farads	Capacitor value	(10 ±) μ Farads
EMF of 1.5 v battery	(±) Volts	EMF of 3 v batteries	(±) Volts
Half time to discharge $t_{1/2}$	Sec	Half time to discharge $t_{1/2}$	Sec
Calculated value of C	μ Farads	Calculated value of C	μ Farads
Per cent difference		Per cent difference	
Time constant to discharge τ	Sec	Time constant to discharge τ	sec
Calculated value of C	μ Farads	Calculated value of C	μ Farads
Per cent difference		Per cent difference	

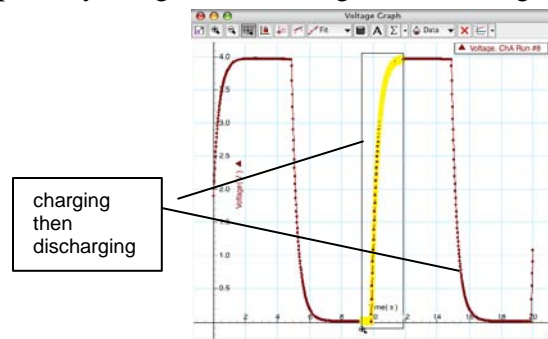
Part III Charging and discharging a capacitor using a AC voltage supply

Rectification Using A Diode (Demonstration)

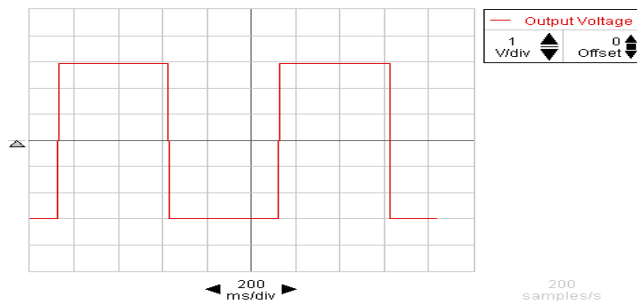
Background:

When a time varying voltage, not a constant voltage from a battery, is applied to the capacitor and resistor circuit, the capacitor repeatedly charges and discharges as the voltage applied repeatedly changes its polarity.

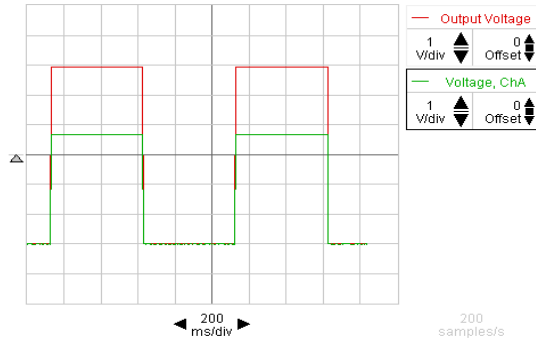
When a time varying voltage with a period much shorter than the time constant of a capacitor is applied to the capacitor, the current flow toward and away from the capacitor limits the range at which the voltage amplitude can change across a resistor attached to the capacitor. For the case when the time constant is long enough, the voltage across a resistor connected to the capacitor remains effectively constant.



This display below is an example of a time-varying wave—a square wave.

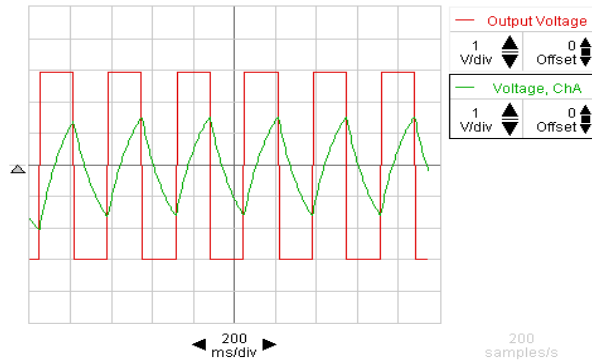


The display below is an example of a square wave applied to a circuit with a diode in it.



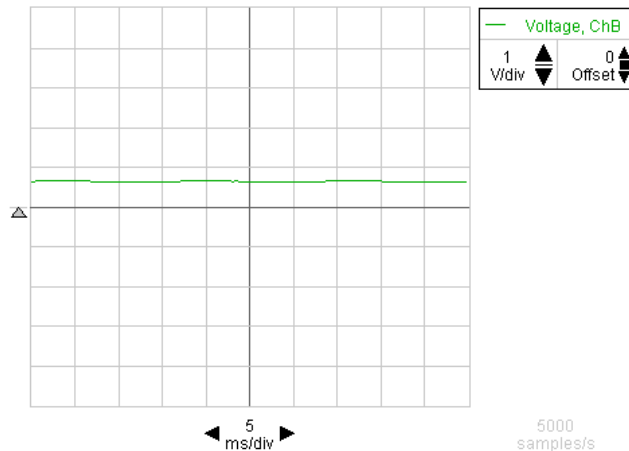
Notice in the circuit above most of the upper half of the wave is missing. When a time varying voltage is applied across a diode—because the diode can only conduct current for a particular polarity, the current flows through the diode for only one-half of the period of the time varying applied voltage.

The display below is an example of a square wave applied a circuit without a diode but containing a resistor and a capacitor in the circuit.

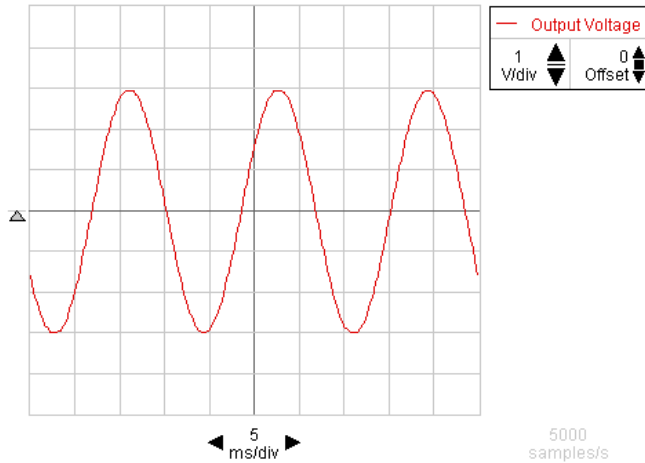


Notice in the circuit above how the capacitor's time constant affects the current flow through the circuit.

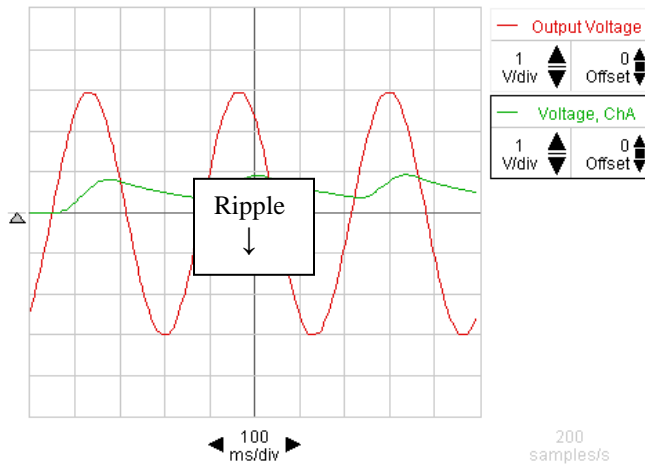
The display below is a square wave applied to a circuit with a diode, a resistor and a capacitor in it. Notice how the wave is nearly flat—this is a DC output from the circuit which has a time varying voltage input.



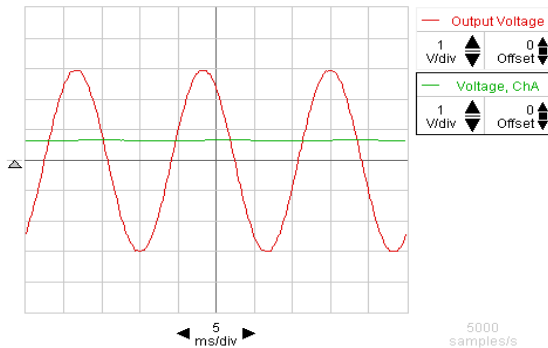
The display below is a time varying voltage input as a sine wave.



In the display below this sine wave input is applied to a circuit with a diode, resistor and capacitor. Notice that the period of the input wave is small enough to allow the capacitor to begin to discharge. The output of this circuit has ripple and is not rectified sufficiently to be considered DC.



In the display below a sine wave input is applied to the same circuit of the display above but the period of the input sine wave is much shorter than in the display above. The capacitor's time constant is so long compared to the period of the input wave that the ripple in the output is very slight and so the output is considered DC.



Part III Charging and discharging a capacitor using a AV voltage supply

Rectification Using A Diode (Demonstration)

Procedure

1. Set up the PASCO 750 Interface and the computer and start *DataStudio*.
2. Connect the Voltage Sensors into Channel A and Channel B on the PASCO 750 Interface. Connect banana plug patch cords into the 'OUTPUT' ports on the interface.
3. Open the *DataStudio* file: **74 Rectifier.ds** The file has a Scope display of 'Voltage, Ch A' and 'Voltage, Ch B' and the Signal Generator window that controls the 'Output'. The Signal Generator is set to output a 3-volt 'Sine Wave' at 2 Hz. Change the frequency to 60 Hz which is the standard frequency from the electric utility company. The output is set to start and stop automatically when you start and stop measuring data.
4. The output voltage on the display is the 60 Hz input to the rectifier that will be constructed on the circuit board. The display in channel B is monitored with the red and black alligators to the 750 interface.
5. Construct the half wave rectifier circuit as shown in the diagram below with the following components: a diode, a 680 ohm resistor and a 2.2 μF capacitor. Connect the red and black alligators to channel A.

Red alligator channel A

AC in Sine wave

Black alligator channel A

Ground from input

6. Determine the period T of an AC wave of frequency $f = 60$ Hz and record it in the data table. Recall $T = 1/f$
7. Determine the time constant for a resistor/capacitor combination of 680 ohms and 2.2 μF and record this in the data table. Recall $\tau = (RC)$.
8. Verify that the period of the AC wave is much shorter than the time constant of the resistor/capacitor combination and record results in data table.
9. Use the "output" channel and channel A to compare the appearance of the wave before and after its rectification, measuring the voltages and record results in the data table.

Red alligator channel A

AC in Sine wave

Black alligator channel A

Ground from input

10. Construct the full-wave rectifier as shown in the diagram using a 680 ohm resistor and a 330 μF capacitor and four diodes.
11. Determine the time constant for a resistor/capacitor combination of 680 ohms and 330 μF and record this in the data table. Recall $\tau = (RC)$.
12. Determine the period T of an AC wave of frequency $f = 60$ Hz and record it in the data table. Recall $T = 1/f$

13. Verify that the period of the AC wave is much shorter than the time constant of the resistor/capacitor combination and record results in data table.
14. Use the oscilloscope to compare the appearance of the wave before and after its rectification, measuring the voltages and record results in the data table.

Part III

Data Charging and discharging a capacitor using a AV voltage supply and Rectification Using A Diode (record in notebook)

Half wave rectifier	Time constant of input wave	Time constant of resistor/capacitor combination	Input Voltage	Output voltage
x	sec	sec	volts	volts
Input voltage appearance		Output voltage appearance		
Full wave rectifier	Time constant of input wave	Time constant of resistor/capacitor combination	Input Voltage	Output voltage
x	sec	sec	volts	volts
Input voltage Appearance		Output voltage Appearance		
Input & Output Voltage of half-wave rectifier circuit		Input & Output Voltage of full-wave rectifier circuit		

Analysis of Data Parts I, II, III

1. The time to half-maximum voltage is how long it takes the capacitor connected to a battery to charge halfway. Based on your experimental results, predict the time when the capacitor is charged to 75% of its maximum (i.e., two half-lives) $t = \underline{\hspace{2cm}} \text{ sec}$
2. Based on the experiment, predict the percentage of the maximum charge on the capacitor connected to a battery after four half-lives $\underline{\hspace{2cm}} \%$

3. The maximum charge for the capacitor connected to one 1.5 volt battery in this experiment is _____ volts
4. The maximum charge for the capacitor connected to two 1.5 volt batteries connected in series in this experiment is _____ volts
5. Some of the factors that could account for the percent difference between the stated and experimental values are _____.
6. The peak voltage of the un-rectified input wave conducted through a half-wave bridge... (circle one choice) *increased, remained the same, decreased...* when it was half-wave rectified as the output wave.
7. The peak voltage of the un-rectified input wave conducted through a full-wave bridge ... (circle one choice) *increased, remained the same, decreased...* when it was full-wave rectified as the output wave.