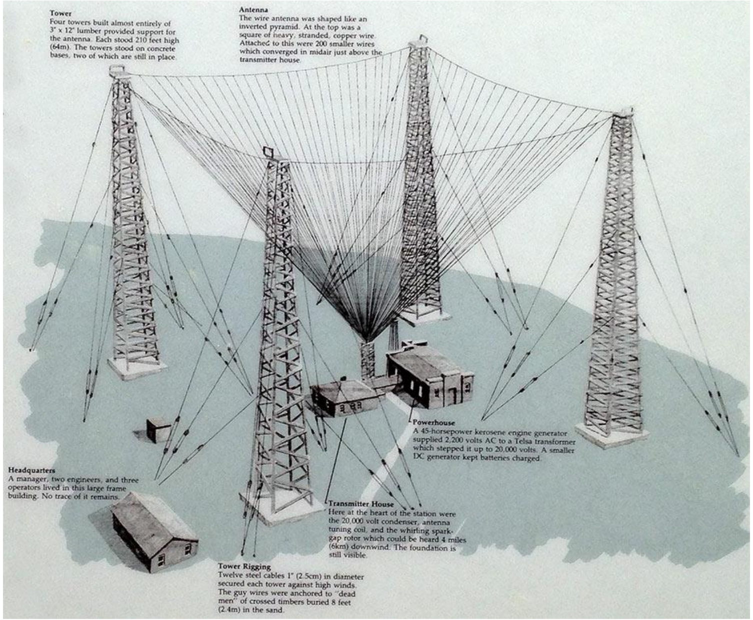
Marconi Wireless Station

South Wellfleet, Cape Cod, MA

January 18, 1903



Electronics - PHYS 2371/2

Calendar of Topics Covered

Physics PHYS 2371/2372, Electronics for Scientists

Don Heiman and Hari Kumarakuru
Northeastern University, Fall 2020

Also see **Course Description** and **Syllabus**

This is a schedule of the topics covered, but it may be modified occasionally (08/13/2020).

Week #	Lectures	Weekly Topics (Chs.)	Homework (Ch-Problem)	Lab Experiments (always look for latest version)
I Sept 9-11	**Wed Lecture** Introduction	Basic Concepts (Ch-2) Ch-16, Digital Multimeters		***Worksheet-1, Electronics Introduction*** (multimeter, voltage sources)
II Sept 16-18	**Wed Lecture** Electronic Basics	Basic Circuit Analysis (Ch-3) Some Simple Circuits (Ch-4) Resistor/ Capacitor (Ch-47/48)	2-8/9, 3-5/6, 4-4/8, 4-13/14	***Worksheet-2, Electronic Basics***
III Sept 23-25	**Wed Lecture** Time-Dependent AC Circuits	The Oscilloscope (Ch-17) AC and Elements of Circuits (Ch-7/8) Circuit Analysis (LRC) (Ch-9/12) Resonance (Ch-10)	7-all, 8-3 12-all	***Worksheet-3, Time-Dependent AC Circuits*** (R, RC, LRC)
IV Sept 30-Oct 2	**Wed Lecture** Semiconductor Devices	Solid State Devices (Ch-40) *p-n* Junction Diodes (Ch-41) Transistors/Circuits (Ch-42-45)	HW Handout	***Worksheet-4, Say Hello (and Goodbye) to the Transistor***

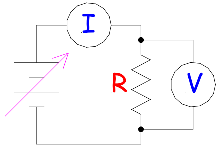
Due next Wednesday, Sept 23
- HW, Chapters 2-4
- Worksheet-2

TODAY

- □ **Quick Review-Basics**
  - DMM meters
- □ **Circuit Analysis**
  - Kirchhoff's Laws (V,I)
- □ **Simple Circuits**
  - reducing complex circuits
  - VOLTAGE DIVIDER
  - capacitors

  (video break - Tesla)
- □ **Lab techniques**
  - collecting data
  - plotting data
  - precision, accuracy, digits
- □ **Worksheet-2, Electronic Basics**

Review Basics

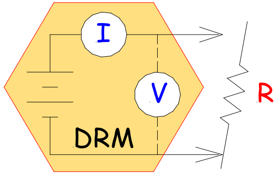


- DVM - digital **volt** meter
  - high resistance, $R_{DVM} >> R$
  - in **PARALLEL** with components
- DCM - digital **current** meter
  - low resistance, $R_{DCM} << R$
  - in **SERIES** with components
- VERY IMPORTANT ! **I = V/R**

  When you apply a voltage
  - resistance determines the current
  - you cannot vary both V and I independently

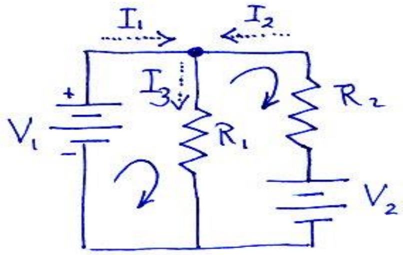
Multimeters

- Ohm Meter - digital **resistance** meter
  - applies a **known current**
  - measures the voltage it takes to produce that current
  - uses Ohm's law to compute **R=V/I**
- IMPORTANT
  - remove resistor from circuit
  - current from a circuit must **not** flow thru resistor



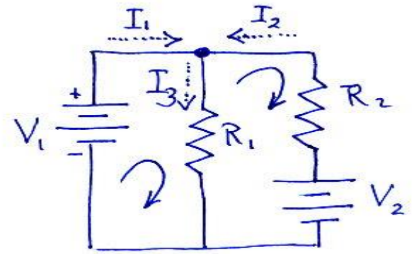
Circuit Analysis

Kirchhoff's Basic Circuit Laws (Ch. 3)



- ❑ **KCL – Kirchhoff's Current Law**
- ❑ **KVL – Kirchhoff's Voltage Law**

Kirchhoff's Basic Circuit Laws



❑ KCL – Kirchhoff's Current Law

$\Sigma I = 0$ at node
Sum of all currents at a point = 0
conservation of current or charge
→ "what goes in must come out"

Set up (draw) current arrow

Define the following

- I into node $I > 0$; positive
- I out of node $I < 0$; negative

Example: $\Sigma I = 0$

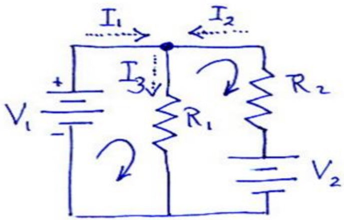
$$I_1 + I_2 - I_3 = 0$$

$$I_1 + I_2 = I_3$$

Note: it's ok that you don't know a priori which direction the current will flow.

After solving the circuit, the currents can have either "+" or "–" signs indicating the true direction.

Kirchhoff's Basic Circuit Laws



❑ KVL – Kirchhoff's Voltage Law

$\Sigma V = 0$ around loop
Voltage must come back to itself around loop
"*you can't get something for nothing*"

1) Set up current directions (dotted curves, as before)
2) Define **loop** directions (solid curves)
3) **Source** **– loop arrow out of positive end, V > 0, positive**
– loop arrow out of negative end, V < 0, negative
4) **Resistor** **– arrows same (current/loop) direction, IR < 0**
– arrows opposite (current/loop) direction, IR > 0

Note: it's ok if you define the loop direction wrong.

Example:

Loop-1, $V_1 - I_3R_1 = 0$ => $V_1 = I_3R_1$
Loop-2, $+I_3R_1 + I_2R_2 - V_2 = 0$ => $V_2 = +I_3R_1 + I_2R_2$
Substitute $V_2 = V_1 + I_2R_2$
(*Large loop* $V_1 + I_2R_2 - V_2 = 0$)

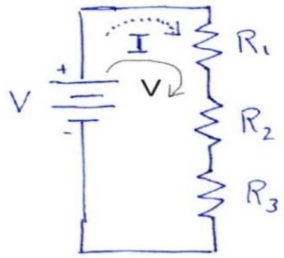
Equivalent Resistance

- **Series Resistors**

around loop – use KVL

$\Sigma V = 0$
$V - IR_1 - IR_2 - IR_3 = 0$
$V = I(R_1 + R_2 + R_3)$
$V = I R_{eff}$

$\mathbf{R_{eff} = R_1 + R_2 + R_3 = \Sigma R_i}$



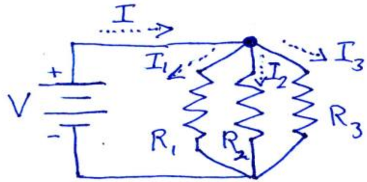
- **Parallel Resistors**

Sum currents at node – use KCL
$\Sigma I = 0$ or $I - I_1 - I_2 - I_3 = 0$

Voltages around loops – use KVL
KVL1 $V - I_1R_1 = 0$, $I_1 = V/R_1$
KVL2 $V - I_2R_2 = 0$, $I_2 = V/R_2$
KVL3 $V - I_3R_3 = 0$, $I_3 = V/R_3$

$I = V/R_1 + V/R_2 + V/R_3$
$= V * (1/R_1 + 1/R_2 + 1/R_3)$
$= V / R_{eff}$

$\mathbf{1/R_{eff} = 1/R_1 + 1/R_2 + 1/R_3 = \Sigma (1/R_i)}$

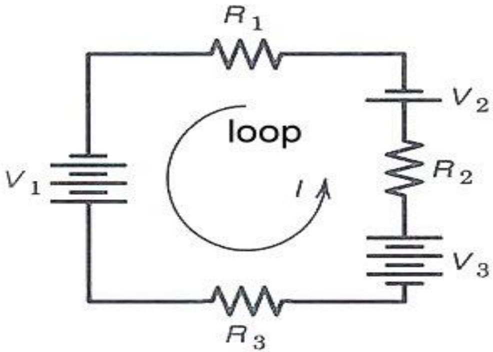


For 2 resistors in parallel

$$R_{eff} = \frac{R_1 R_2}{R_1 + R_2}$$

Simple Circuit

Problem 3-7



What is I for the circuit in Figure 3-15?

V_1=20 V, V_2=5 V, V_3=15 V

R_1=100 Ω, R_2=25 Ω, R_3=250 Ω

Apply KVL – no nodes

loop and current in same direction

$V_1 - IR_3 + V_3 - IR_2 - V_2 - IR_1 = 0$

$V_1 + V_3 - V_2 = I (R_3 + R_2 + R_1)$

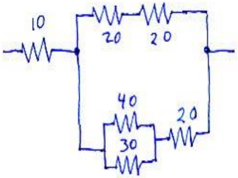
$I = (V_1 + V_3 - V_2) / (R_3 + R_2 + R_1)$

$I = (20\ V + 15\ V - 5\ V) / (100\ \Omega + 25\ \Omega + 250\ \Omega)$

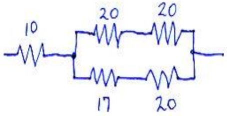
I = 30 V / 375 Ω = 0.080 A = **80 mA**

Equivalent Resistor Circuit

❑ Reducing Complex Circuits

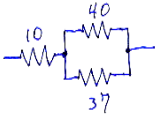


R_{e1} = 40Ω*30Ω / (40Ω+30Ω) = 1200/70 = 17 Ω

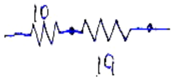


R_{e2} = 20Ω + 20Ω = 40 Ω

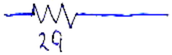
R_{e3} = 17Ω + 20Ω = 37 Ω



R_{e4} = 40Ω*37Ω / (40Ω+37Ω) = 1480/77 = 19 Ω



R_{total} = 10 Ω + 19 Ω **= 29 Ω**



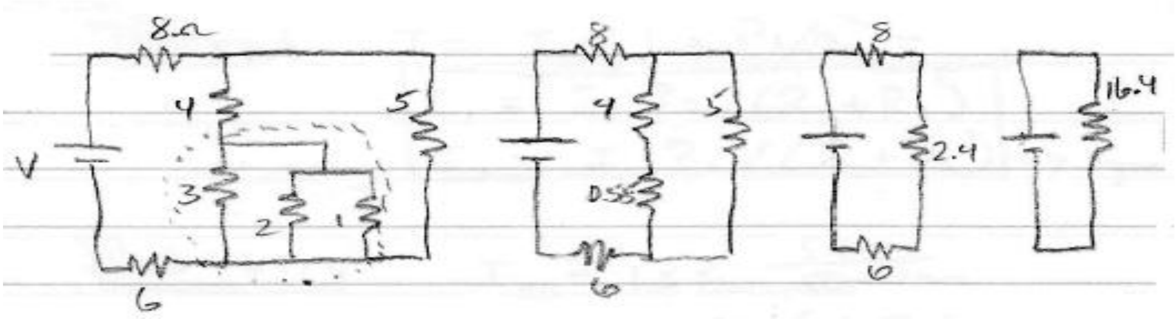
Simplifying Circuits

- **Reducing Complex Circuits**

Example: Given V=10 V, find the battery current I

$R_{e1} = (1/3\Omega + 1/2\Omega + 1/1\Omega)^{-1} = 0.55\ \Omega$
$R_{e2} = (1/4.55\Omega + 1/5\Omega)^{-1} = 2.4\ \Omega$
$R_{total} = 16.4\ \Omega$

I $= V / R_{total} = 10\ V / 16.4\ \Omega$ **= 0.61 A**



Voltage Divider Equation

KVL1

$V_{in} - IR_1 - IR_2 = 0$

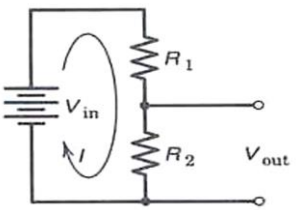
$V_{in} = I\ (R_1+R_2\ )$

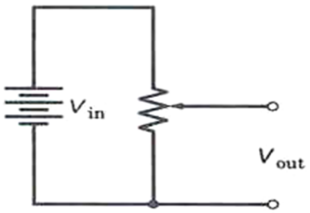
$\mathbf{I\ = V_{in}\ /\ (R_1+R_2)}$

KVL2

$- V_{out} + IR_2 = 0$

$\mathbf{V_{out} = IR_2}$





$$V_{out} = V_{in} \frac{R_2}{R_1 + R_2}$$

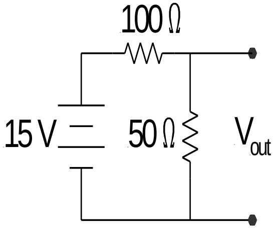
Imagine a wire with a variable resistance.

Problem ~4-9

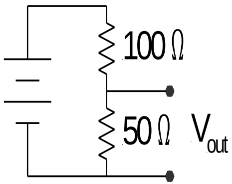
Find the output voltage.

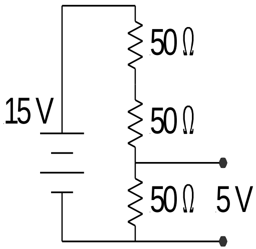
$$V_{out} = 15\,V \frac{50\,\Omega}{100\,\Omega + 50\,\Omega}$$

$$= 15\,V\left(\frac{50\,\Omega}{150\,\Omega}\right) = 5\,V$$



Redraw circuit

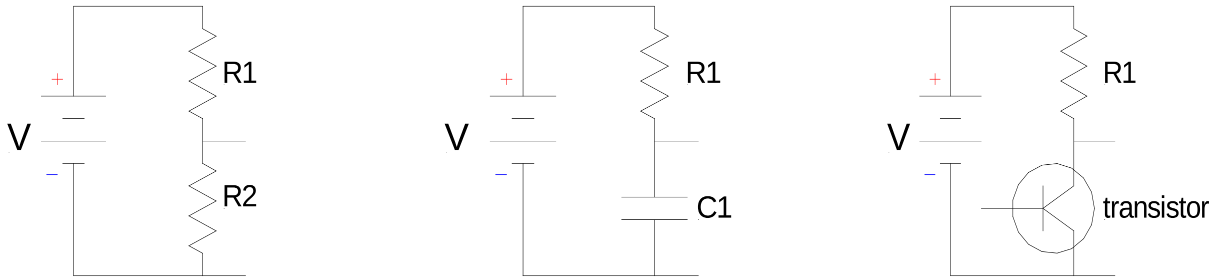




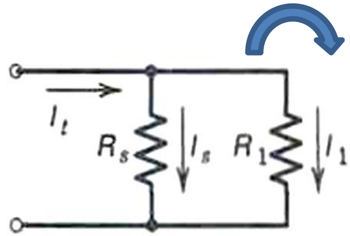
Voltage Divider with Other Components

You will see voltage dividers many many many times in electronics.

Either R1 or R2 many be replaced by a capacitor, inductor, transistor, etc.



Current Divider Circuit



KVL $- I_1R_1 + I_sR_s = 0$ CW around loop

or $I_s = I_1 R_1/R_s$

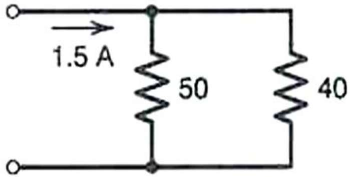
KCL $I_t = I_s + I_1$ at node

$I_t = I_1 R_1/R_s + I_1$

$\mathbf{I_1 = I_t \ R_s/(R_s+R_1)}$

$\mathbf{I_s = I_t \ R_1/(R_s+R_1)}$ by symmetry

current divider!



Problem 4-13 Find the currents.

$I_{50} = 1.5 \text{ A} * 40\ \Omega / (50\ \Omega + 40\ \Omega)$

$= 1.5 \text{ A} * 0.44$

$\mathbf{I_{50} = 0.67\ A}$

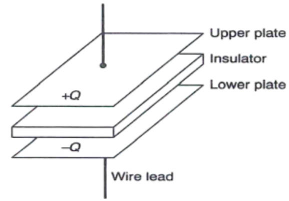
$\mathbf{I_{40} = 0.83\ A}$

Q: which resistor has the highest current?

Capacitors

$C = \varepsilon A/d$; Area, distance between

$C=Q/V$ or $V=Q/C$ or **$Q = CV$**



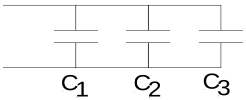
Field-effect device

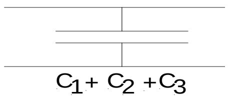
Electric field of charge +Q on one plate, forces the opposite charge -Q away from the other plate.

Parallel Capacitors

$C_{eff} = \varepsilon\,(A_1 + A_2 + A_3)/d$ more area

$\mathbf{C_{eff} = C_1 + C_2 + C_3 = \Sigma C_i}$





Series Capacitors

$V_1 = Q_1/C_1,\ V_2 = Q_2/C_2$

but $\mathbf{Q_1 = Q_2 = Q}$

$V_1 = Q/C_1,\ V_2 = Q/C_2$

$V = V_1 + V_2$

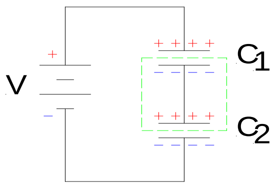
$= Q/C_1 + Q/C_2$

Also, $V = Q/C_{eff}$

or $Q/C_{eff} = Q/C_1 + Q/C_2$

$\mathbf{1/C_{eff} = 1/C_1 + 1/C_2}$

$\mathbf{C_{eff} = (\Sigma\, 1/C_i)^{-1}}$



Sum values: series resistors – parallel capacitors

Sum reciprocals: parallel resistors – series capacitors

Break – Video

Tesla (0-9:00)

Some Experimental Details

Accuracy versus Precision

1. Precision – how ***exact*** is a measurement, or how "*fine*" is the scale (# of significant figures).

Suppose you measure a resistor with a digital ohmmeter. The ohmmeter reads 1.53483 Ω. This number has a high *precision*. However, it may not represent the "true" resistance as the wires connecting the resistor and ohmmeter have some small resistance that contributes to the measurement.

2. Accuracy – how ***close*** is the measurement to the "***true***" value.

Accuracy is a measure of the *correctness* of the measurement. To determine a more *accurate* value for the resistor's resistance, you subtract the resistance of the wires.

Significant Digits and Round-off

Rule: round off a computed answer to same number of significant digits as the input number with the smallest number of significant digits.

Calculators and digital meters produce a much larger number of significant digits than is usually justified. The answer from a calculator has very high *precision*, typically to 8 or 10 digits. In experiments, the number of significant digits is usually much less than this. Suppose you want to divide two values obtained from an experiment – one value has **five** significant digits and the other value has **three**. Although the calculator gives 8 significant digits, the answer is only significant to the smallest number of significant digits, only **three**. You must round-off the calculator number to three significant digits while the fourth significant figure is dropped. When the fourth significant figure is greater than 5, the third significant figure is incremented one unit.

Example: V=9.2643 V and I=1.49 A

R = 9.2643/1.49 = 6.2**1**76510 Ω

R = 6.22 Ω round up the 1 to a 2

It is useful to write numbers in *scientific notation*. For example, the number 0.0000325 would be expressed as $3.25\text{x}10^{-5}$. When measuring quantities such as voltage, it is best express the values in *engineering notation*, which has powers of 10 in increments of 3. Thus, 0.0000325 volts becomes $32.5\text{x}10^{-6}$ V, or **32.5 µV**.

Hints for collecting data

1. **Take large steps at first**

   Take 3-5 point up to the maximum.

   e.g. use V=0, 0.3V_{MAX}, 0.6V_{MAX}, and V_{MAX}

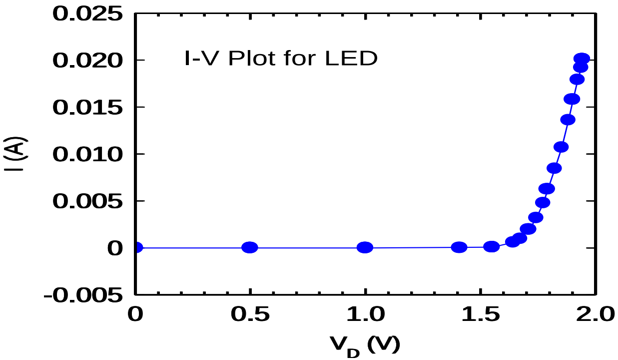
2. **Plot Data**

   See where you need to fill in data points.

3. **Fill in points**

4. **Connect points with a curve,**

   unless you have a theory curve.



Worksheet-2, Electronic Basics

DMM

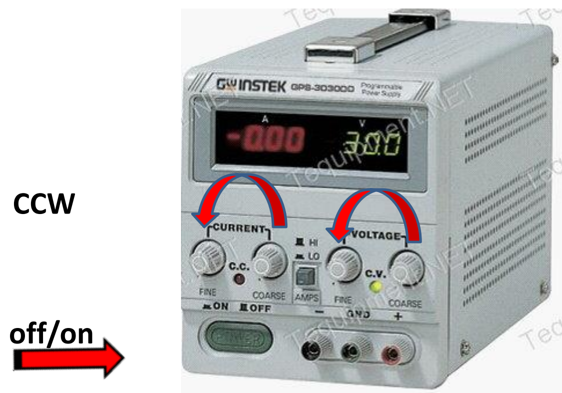
Always us the scale with the most number of digits.

Push left-most button that does not show overflow (blinking display).

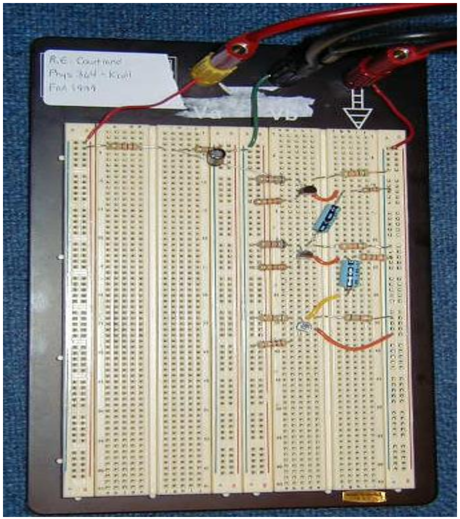
Gives highest precision and usually a higher accuracy

Power Supply

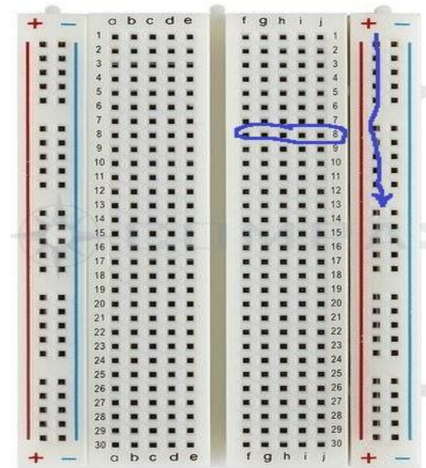
1. **Make sure the PS is off**
2. **Turn all 4 knobs counter-clockwise**
3. **Turn on PS**
4. **Turn up current knob up about one-half**
5. **Adjust voltage knobs**



Protoboard (breadboard) Wiring



Typical layout with voltage on the red/blue long rows.



The 5-hole rows are electrically connected horizontally.

The long red/blue rows are connected vertically.

Worksheet-2, Electronic Basics

Physics PHYS 2371/2372, Electronics for Scientists

Don Heiman, Northeastern University

I. Voltage Divider – Here, you will investigate *series resistors*.
Note: you will see voltage dividers over and over again in circuits. Most of those will not contain two resistors, but instead may contain a resistor and another component (capacitor, transistor, etc.).

Choose two resistors with different values in the kΩ range and arrange them in series with the power supply. Next, apply a voltage and measure the voltage across each resistor using the first DMM. Compare the measured voltage ratio to the ratio resistances of resistances.

V_{R1}/V_{R2} = __**3.42**____________________ R_1/R_2 = __**3.12**______________________

These two resistors in series make a ***Voltage Divider***.

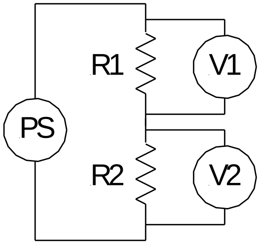
II. Capacitors – Connect two different capacitors in the 10-100 µF range in series and to the power supply. **Make sure you use the correct polarity on the electrolytic capacitors (longer lead is positive).** Set up the two DVMs to measure the voltages across each capacitor. Turn on the power supply and measure the voltages quickly after the voltage is applied.

1. Compare your value for voltage ratio to the capacitance ratio.

V_{C1}/V_{C2} = ___**1.62**____________________ C_1/C_2 = __**0.83**_____________________

……….

I. Voltage Divider – Here, you will investigate *series resistors*.
Note: you will see voltage dividers over and over again in circuits. Most of those will not contain two resistors, but instead may contain a resistor and another component (capacitor, transistor, etc.).

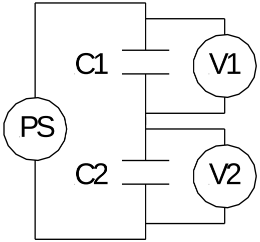


Choose two resistors with different values in the kΩ range and arrange them in series with the power supply. Next, apply a voltage and measure the voltage across each resistor using the first DMM. Compare the measured voltage ratio to the ratio resistances of resistances.

V_{R1}/V_{R2} = ______________ R_1/R_2 = __________________

These two resistors in series make a ***Voltage Divider***.

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$

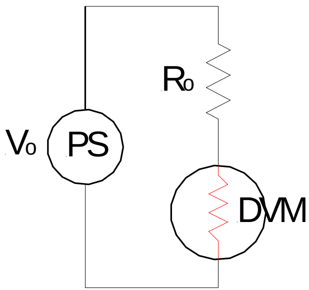


II. Capacitors – Connect two different capacitors in the 10-100 μF range in series and to the power supply. **Make sure you use the correct polarity on the electrolytic capacitors (longer lead is positive).** Set up the two DVMs to measure the voltages across each capacitor. Turn on the power supply and measure the voltages quickly after the voltage is applied.

1. Compare your value for voltage ratio to the capacitance ratio.

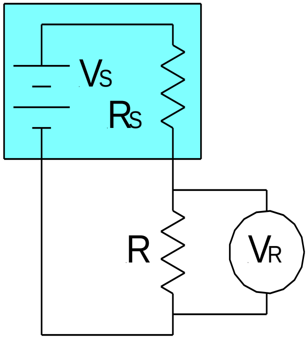
V_{C1}/V_{C2} = _______________ C_1/C_2 = __________________

III. Voltmeter Input Impedance – All voltmeters have an effective resistance, referred to as the *input impedance*. When placed in a circuit, the added resistance of the meter will draw a small amount of current, in effect, changing the circuit. Determine the input impedance of the DVM by using a voltage divider network with the DVM in place of one resistor and use an $R_o \geq 1\ \mathrm{M\Omega}$ as the other resistor.
If you put a second DVM across R_o, what effect will that have?



$$V_{DVM} = V_o \frac{R_{DVM}}{R_o + R_{DVM}}$$

IV. Battery/Power Supply Internal Impedance – All power sources have a maximum voltage and current that they are capable of producing. For example, leaving the output terminals open produces the maximum voltage, while shorting (R ~ 0) the output terminals produces the maximum current. In effect, power sources have an internal resistance that limits the current. Determine the *internal impedance* R_S of the battery or power supply using a voltage divider network as before, where the source impedance is one resistor and the other is an R=10 Ω (P=1 W) resistor. Hint: measure the source voltage (V_o) by disconnecting the 10 Ω resistor.



Lab Experiments

or "*No student left behind*"

Please ask questions !

Fin