**Instruction Manual
for the PASCO scientific
Model SF-9584A**

LOW VOLTAGE AC/DC POWER SUPPLY

LOW VOLTAGE AC/DC POWER SUPPLY

PASCO *scientific*
SF-9584A

C E   V   A

AC

VOLTAGE ADJUST   **CURRENT ADJUST**

DC

MAX DC CURRRENT ⚠

10 A
6 A

12 V   24 V

− 0 – 24 V +

OFF

ON

10 12 14 16
8   18
6   20
4   22
2   24

RESET

2-24 V
6 A MAX
⚠

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Table of Contents

Copyright, Warranty and Equipment Return

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Credits
Author: Hans Frederiksen
Editor: Sunny Bishop

Equipment Return

Should the product have to be returned to PASCO scientific, for whatever reason, notify PASCO scientific by letter or phone BEFORE returning the product. Upon notification, the return authorization and shipping instruc-tions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsi-bility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The carton must be strong enough for the item shipped.

② Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material can not shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

Address: PASCO scientific
             10101 Foothills Blvd.
             P.O. Box 619011
             Roseville, CA 95678-9011

Phone: (916) 786-3800

FAX: (916) 786-8905

email: techsupp@PASCO.com

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Introduction

The PASCO scientific Model SF-9584A Low Voltage AC/DC Power Supply provides two outputs: a regulated DC output and an unregulated AC output. The DC output can be delivered in two modes: constant voltage mode and constant current mode.

The Low Voltage AC/DC Power Supply is intended for supervised classroom use.

Operation

DC Output Operation:

① Flip the power ON/OFF switch to OFF.

② Plug the power cord into a grounded outlet of the appropriate voltage :
Model SF-9584A, 115 V AC (78–130 V AC), 60 Hz
or
Model SF-9584A-230, 230 V AC (200 –242 V AC), 50 Hz.

③ Connect the 0 –24 V DC OUTPUT terminals of the power supply to the circuit. (Connecting wires are not provided with the power supply.)

④ Rotate the DC VOLTAGE ADJUST knob and the DC CURRENT ADJUST knob fully counterclockwise.

⑤ Flip the power ON/OFF switch to ON. The switch will light to show that the power supply is on.

⑥ Constant Voltage Mode: Turn the DC CURRENT ADJUST knob fully clockwise. Then adjust the DC VOLTAGE ADJUST knob to obtain the desired output voltage, as indicated on the meter. The output current is displayed on the current meter.

⑦ Constant Current Mode: Turn the DC VOLTAGE ADJUST knob fully clockwise. Adjust the DC CURRENT ADJUST knob to obtain the desired output current, as indicated on the meter. The output voltage is displayed on the voltage meter.

⚠ DC Output, Limitations

The DC output is regulated for both constant-voltage and constant–current operation.

Constant Voltage mode:
The voltage is continuously variable from 0 –24 V DC. The maximum load drawn in the range from 0–12 V DC is 10 A. In the 12 - 24 V range, a load of 10–6 A may be drawn as the maximum load. At 24 V, the maximum is 6 A. (See the illustration printed on the front panel, "Max. DC Current," or Figure 1.)

Constant Current mode:
The load may be varied from 1–10 A in the 1–12 V DC range. At 12 V, the DC range is variable from 1–10 A. At 24 V, the range decreases to 0–6 A. (See the illustration printed on the front panel, "Max. DC Current," or Figure 1.) A digital meter allows monitoring of both voltage and current for the DC output.
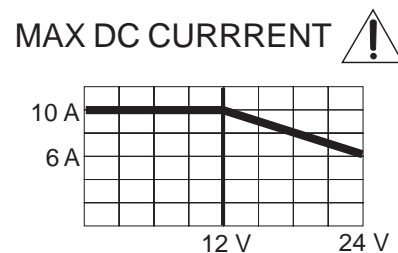

Figure 1. Maximum DC Current

AC Output Operation:

① Flip the power ON/OFF switch to OFF.

② Plug the power cord into a grounded outlet of the appropriate voltage :
Model SF-9584A, 115 V AC (78 - 130 V AC), 60 Hz
or
Model SF-9584A-230, 230 V AC (200 - 242 V AC), 50 Hz.

③ Connect the 2–24 V AC OUTPUT terminals of the power supply to the circuit. (Connecting wires are not provided with the power supply.)

④ Rotate the AC VOLTAGE ADJUST knob to the 2–V position.

⑤ Flip the power ON/OFF switch to ON. The switch will light to show that the power supply is on.

⑥ Set the AC VOLTAGE ADJUST knob to the desired setting.

⚠ **AC Output Limitations**

The AC output is unregulated and is adjustable in 2-V increments from 2 to 24 V AC, with a maximum output current of 6 amperes. This output is protected by a 6-amp circuit breaker. If the maximum current output is exceeded, the circuit breaker button below the power switch will pop out. (See Figure 2.)
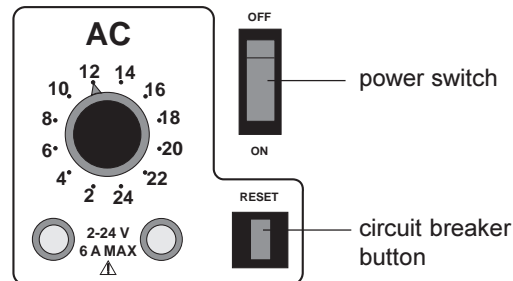
Figure 2. Location of Circuit Breaker Button

The circuit breaker can be reset by simply pushing the button back in. It may be necessary to reduce the AC output voltage or the load connected to the AC output in order to resume operation.

➤ **NOTE:** If at any time the power supply fails to come on, or if it shuts down during operation due to excessive current, check the following: If the ON/OFF switch does not light when unit is plugged into the appropriate power source and the switch is turned ON, check the fuse on the back of the unit. If it is blown, replace it only with a similarly rated fuse (Model SF-9584A— 8A Slo-Blo fuse, Model SF-9584A-230— 4A Slo-Blo fuse).

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Equipment Specifications

Specifications:

Outputs:

DC: regulated for both constant–voltage and constant–current operation. Both current and voltage continuously variable over the range 0–24 V DC and 0–10 amperes maximum. Independent floating ground reference.

AC: 2 to 24 V (rms) AC, unregulated, selectable in 2–V increments, current up to 6 amperes. Output protected from overload by a 6-amp thermally-activated circuit breaker. Independent floating ground reference.

> ➤ NOTE: Both DC and AC outputs are available simultaneously on separate floating output terminals. Either one of the DC output terminals can be connected to either one of the AC output terminals to form a composite signal without damage to the unit.

Line Regulation:

Less than 1% change in DC output voltage or current for full range change in line voltage. AC output not regulated.

Load Regulations:

Better than 1% no-load to full-load on the DC output voltage or current. AC output not regulated.

Ripple and Noise:

Less than 25 mV pp on DC output.

Metering:

DC voltage and DC current
Accuracy is +1% ± 2 L.S.D.

Line Voltage Requirement:

78–130 V AC, 60 Hz (model SF-9584A)
200–242 V AC, 50 Hz (model SF-9584A - 230)

Power Requirement:

DC and AC: Maximum 350 W
DC only: Maximum 175 W
AC only: Maximum 175 W

Fuse:

8 A Slo-Blo—(model SF-9584A)

4 A Slo-Blo—(model SF-9584A-230)

Size:

118 x 298 x 229 mm (H x W x D including controls)

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Notes:

Schematics and Parts Lists

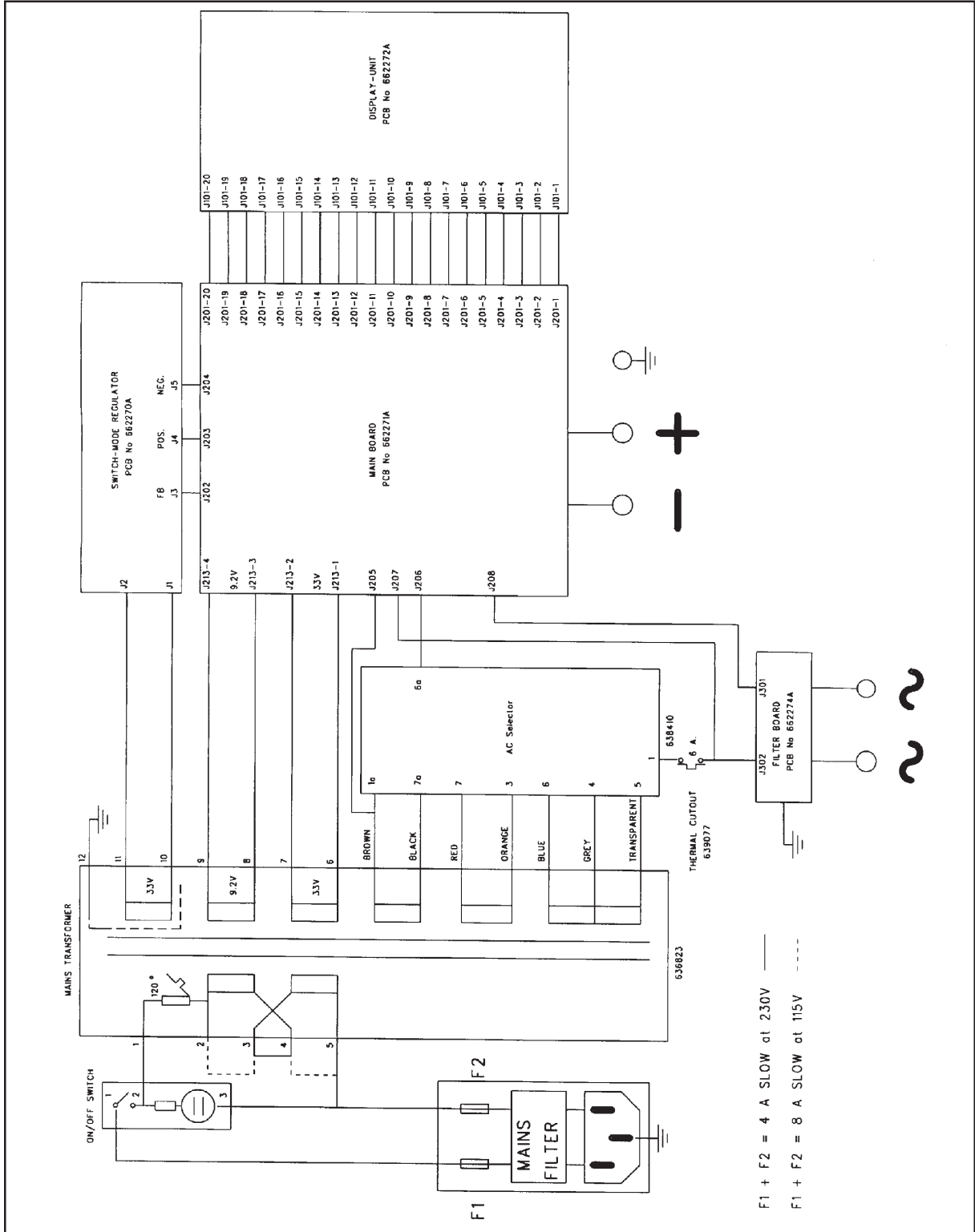➤ **Caution:** *If repairs are needed, they should be performed only by experienced personnel.*
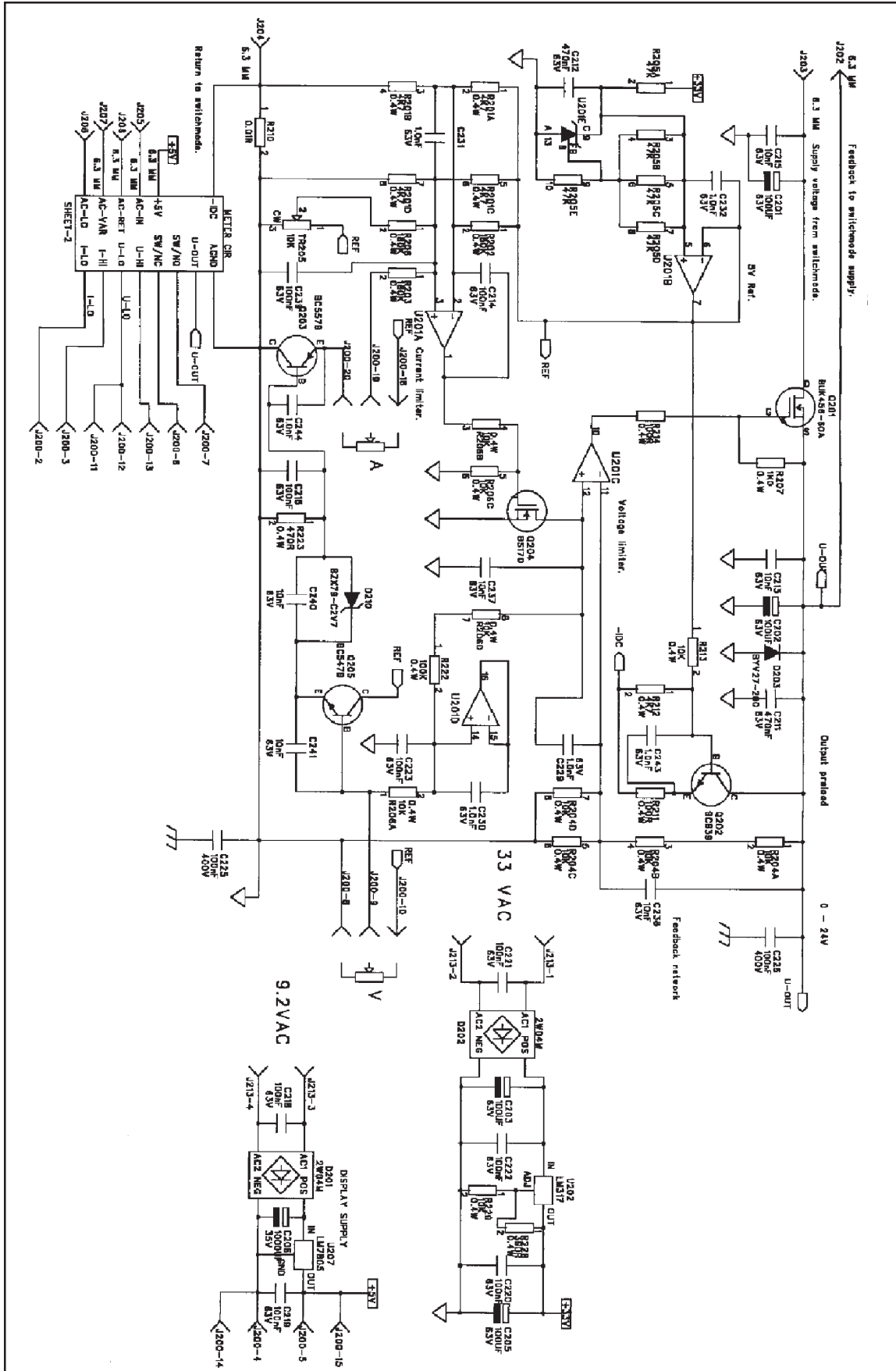

Figure 2. Schematic Overview

Figure 3. Main Board

Parts List – Main Board

Item	Reference	Part Name	Value			Qty	Stock No.
1	R201	RESISTOR	4K7	250V	0.4W	1	601074
2	R204 R206	RESISTOR	10K	250V	0.4W	2	601082
3	R220-221	RESISTOR	10K	250V	0.4W	2	601083
4	R205	RESISTOR	47K	250V	0.4W	1	601099
5	R216 R219	RESISTOR	100K	250V	0.4W	2	601106
6	R211 R214 R217	RESISTOR	100R	250V	0.4W	3	6030701
7	R227	RESISTOR	150R	250V	0.4W	1	6030801
8	R228	RESISTOR	390R	250V	0.4W	1	6031051
9	R218 R223	RESISTOR	470R	250V	0.4W	2	6031101
10	R226	RESISTOR	680R	250V	0.4W	1	6031201
11	R207 R230	RESISTOR	IK0	250V	0.4W	2	6031301
12	R212	RESISTOR	4K7	250V	0.4W	1	6031701
13	R213 R229	RESISTOR	10K	250V	0.4W	2	6031901
14	R222	RESISTOR	100K	250V	0.4W	1	6032501
15	R202-203 R208	RESISTOR	180K	250V	0.4W	3	6032651
16	R224	RESISTOR	IM0	250V	0.4W	1	6033101
17	R210 R215	RESISTOR	0.01R	20mV	2W	2	604301
18	TR201-202	TRIMPOT HORIZ	220R	250V	0.lW	2	605935
19	TR203-205	TRIMPOT HORIZ	10K	250V	0.lW	3	605960
20	C229-234 C243-244	CERAMIC CAP	1.0nF	63V		8	611890
21	C213 C215 C235 C237-238 C240-241	CERAMIC CAP	10nF	63V		7	612010
22	C224-227	STACK FOIL CAP	100nF	400V		4	613170
23	C214 C216-223 C228 C239	STACK FOIL CAP	100nF	63V		11	613450
24	C211-212	STACK FOIL CAP	470nF	63V		2	613530
25	C207-210 C236	ELECTROLYT CAP	4.7UF	25V		5	615643
26	C201-205	ELECTROLYT CAP	100UF	63V		5	615785
27	C206	ELECTROLYT CAP	1000UF	35V		1	616003
28	D203	DIODE	BYV27-200	200V	2A	1	623267
29	D205-209	DIODE	lN4148	75V	0.2A	5	623300
30	D201-202	DIODE	2W04M	400V	2A	2	623665
31	D210	ZENER-DIODE	BZX79-C2V7	2.7V	0.5W	1	624060
32	Q205	NPN TRANSISTOR	BC547B	50V	0.lA	1	624710
33	Q203	PNP TRANSISTOR	BC557B	50V	0.2A	1	624720
34	Q202	NPN TRANSISTOR	BC639	100V	1.5A	1	624750
35	Q201	Nch MOSFET	BUK456-60A	60V	52A	1	625690
36	Q204	Nch MOSFET	BS170	60V	0.5A	1	626120
37	U204	DualOpAmp	LTll12	30V	10mA	1	630211
38	U201	IC	LM614	36V	0.3mA	1	631214
39	U202	VOLTAGE REGULATOR	LM317	40V	lA	1	632130
40	U205	VOLTAGE REGULATOR	LM78L05	35V	0.1A	1	632430
41	U207	VOLTAGE REGULATOR	LM7805	35V	1.5A	1	632533
42	U206	RAIL SPLITTER	TLE2426CLP	40V	0.08A	1	634941
43	RE201-202	RELAY 5V	M4-5H	125V/30W 1A		2	637428
44	J202-208	CONNECTOR	6.3 MM			7	641245
45	J200	3M-929 20 PIN	20 PIN			1	641321
46	J213	STOCKO MKS4	4 PIN			1	641357

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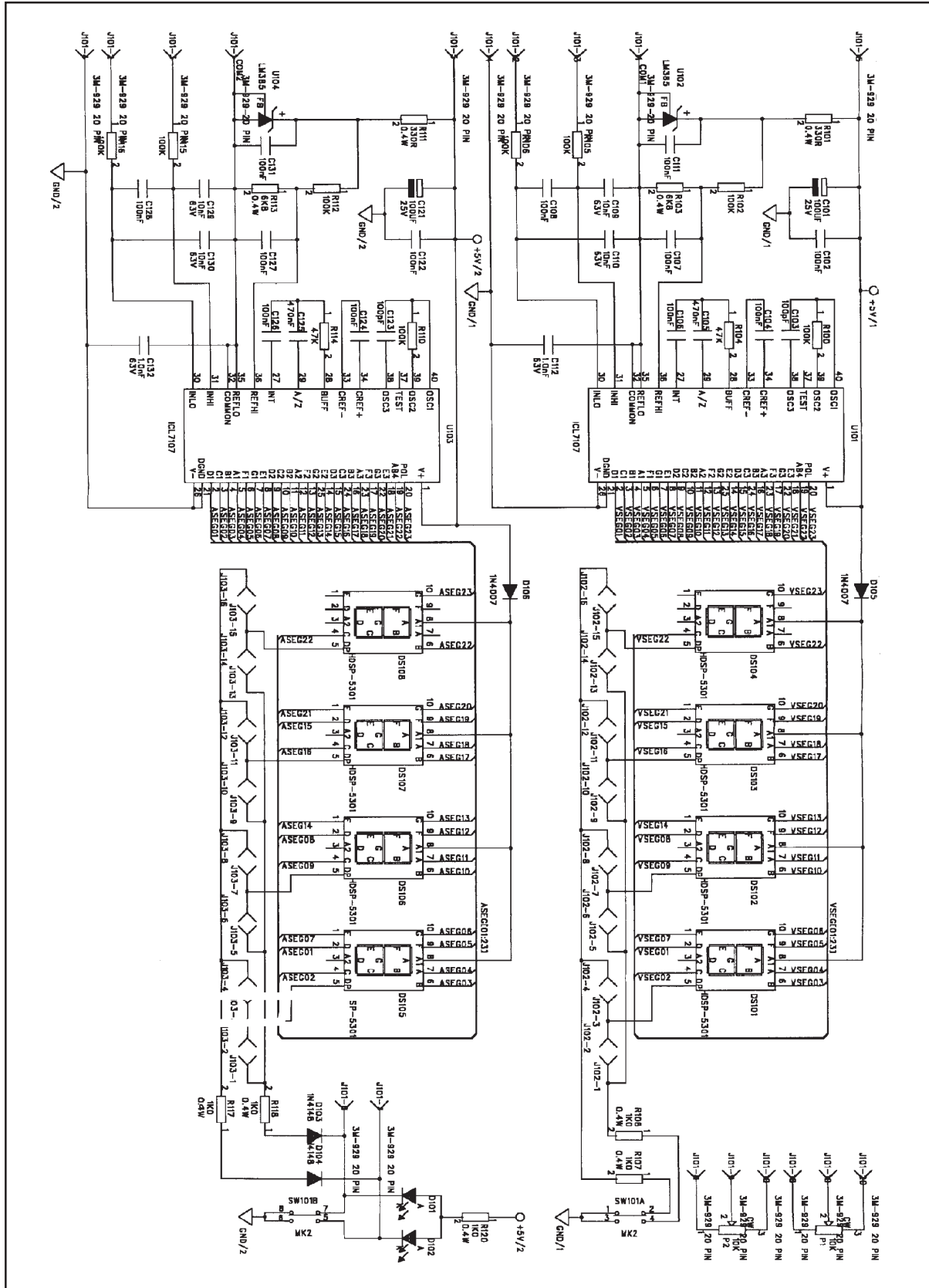
Figure 4. Display Unit

Parts List – Display Unit

Item	Reference	Part Name	Value			Qty	Stock No.
1	R101 R111	RESISTOR	330R	250V	0.4W	2	6031001
2	R107-108 R117-118 R120	RESISTOR	1K0	250V	0.4W	5	6031301
3	R103 R113	RESISTOR	6K8	250V	0.4W	2	6031801
4	R104 R114	RESISTOR	47K	250V	0.4W	2	6032301
5	R100 R102 R105-106 R110 R112 R115-116	RESISTOR	100K	250V	0.4W	8	6032501
6	P1-2	POTMETER	10K	300V	1.5W	2	608251
7	C103 C123	CERAMIC CAP	100pF	63V		2	611770
8	C112 C132	CERAMIC CAP	1.0nF	63V		2	611890
9	C109-110 C129-130	CERAMIC CAP	10nF	63V		4	612010
10	C102 C104 C106-10 C111 C122 C124 C126-128 C131	STACK FOILCAP	100nF	63V		12	613450
11	C105 C125	STACK FOIL CAP	470nF	63V		2	613530
12	C101 C121	ELECTROLYT CAP	100UF	25V		2	616440
13	D101-102	LED	HLMP-1719	2V	2mA	2	622000
14	DS101-108	DISPLAY	HDSP-5301	2V	20mA	8	622940
15	D103-104	DIODE	1N4148	75V	0.2A	2	623300
16	D105-106	DIODE	1N4007	700V	1A	2	623390
17	U102 U104	VOLTAGE REF.	LM385	20mA		2	631185
18	U101 U103	IC	ICL7107	9V		2	635057
19	SW101	SWITCH LOCKING	MK2	120V	250mA	1	638031
20	J102-103	HEADER	16 PIN	500V	2.5A	2	641029
21	J101	3M-929	20 PIN	20 PIN		1	641321
30	U101 U103	TULIPAN	SOK	40 PIN		2	635539
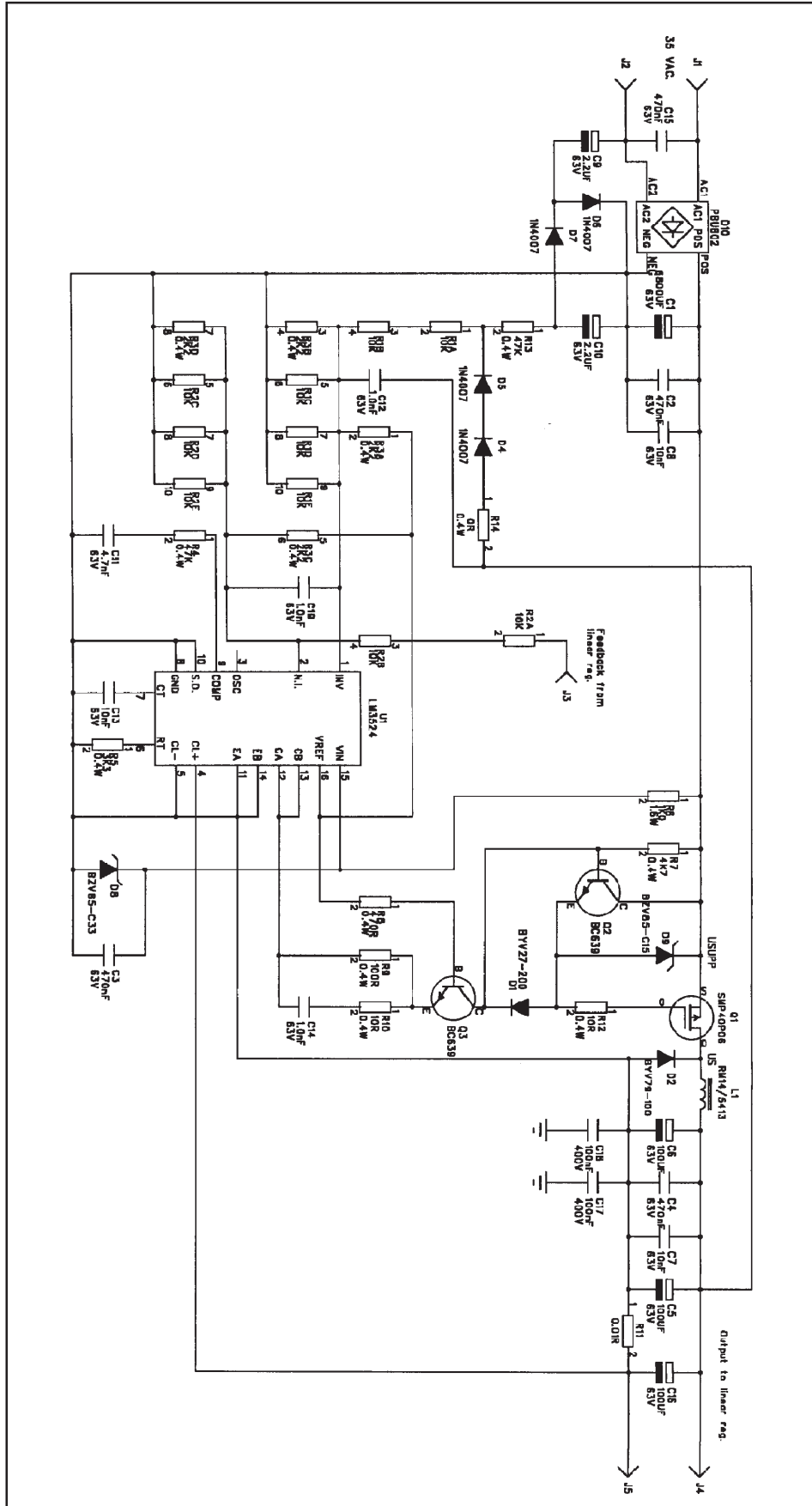
Figure 5. Switch-Mode Regulator

Parts List – Switch-Mode Regulator

Item	Reference	Part Name	Value			Qty	Stock No.
1	R3	RESISTOR	2K2	250V	0.4W	1	601066
2	Rl-2	RESISTOR	10K	250V	0.4W	2	601083
3	R14	RESISTOR	0R	250V	0.4W	1	6020901
4	R10 R12	RESISTOR	10R	250V	0.4W	2	6030101
5	R9	RESISTOR	100R	250V	0.4W	1	6030701
6	R8	RESISTOR	470R	250V	0.4W	1	6031101
7	R5	RESISTOR	3K3	250V	0.4W	1	6031601
8	R7	RESISTOR	4K7	250V	0.4W	1	6031701
9	R4 R13	RESISTOR	47K	250V	0.4W	2	6032301
10	R6	RESISTOR	IK0	500V	1.6W	1	603810
11	Rll	RESISTOR	0.01R	20mV	2W	1	604301
12	CI2 C14 C19	CERAMIC CAP	1.0nF	63V		3	611890
13	Cll	CERAMIC CAP	4.7nF	63V		1	611970
14	C7-8 C13	CERAMIC CAP	10nF	63V		3	612010
15	C17-18	STACK FOIL CAP	100nF	400V		2	613170
16	C2-4 C15	STACK FOIL CAP	470nF	63V		4	613530
17	C9-10	ELECTROLYT CAP	2.2UF	63V		2	615622
18	C5-6 C16	ELECTROLYT CAP	100UF	63V		3	615785
19	Cl	ELECTROLYT	CAP	6800UF	63V	1	616102
20	Dl	DIODE	BYV27-200	200V	2A	1	623267
21	D2	ULTRA FAST DIODE	BYV79-100	100V	14A	1	623268
22	D4-7	DIODE	lN4007	700V	lA	4	623390
23	D10	DIODE BRIDGE	PBU802	100V	8A	1	623685
24	D9	ZENER-DIODE	BZV85-C15	15V	1.0W	1	624515
25	D8	ZENER-DIODE	BZV85-C33	33V	1.0W	1	624533
26	Q2-3	NPN TRANSISTOR	BC639	100V	1.5A	2	624750
27	Ql	Pch MOSFET	SMP40P06	60V	40A	1	626110
28	Ul	IC	LM3524	40V		1	632350
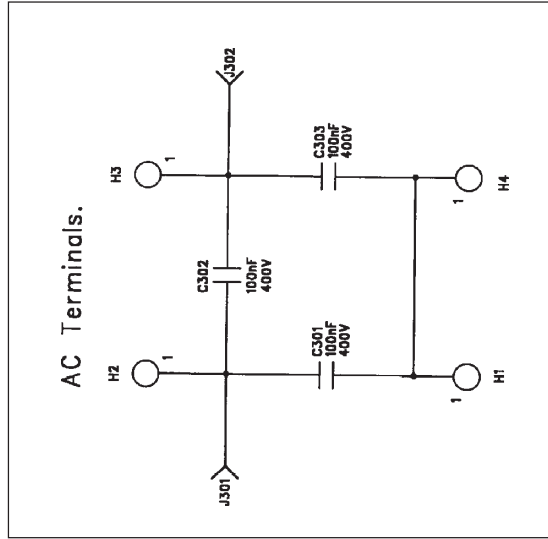
Figure 6. Filter Board

Parts List – Filter Board

Item	Reference	Part Name	Value		Qty	Stock No.
1	H1-4				4	
2	C301-303	STACK FOIL CAP	100NF	400V	3	613170

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@PASCO.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is computer/software related, note:

   - Title and revision date of software;

   - Type of computer (make, model, speed);

   - Type of external cables/peripherals.

➤ If your problem is with the PASCO apparatus, note:

   - Title and model number (usually listed on the label);

   - Approximate age of apparatus;

   - A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.);

   - If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

   - Part number and revision (listed by month and year on the front cover);

   - Have the manual at hand to discuss your questions.

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**Instruction Sheet
for the PASCO
Model CI-6552A**

POWER AMPLIFIER II
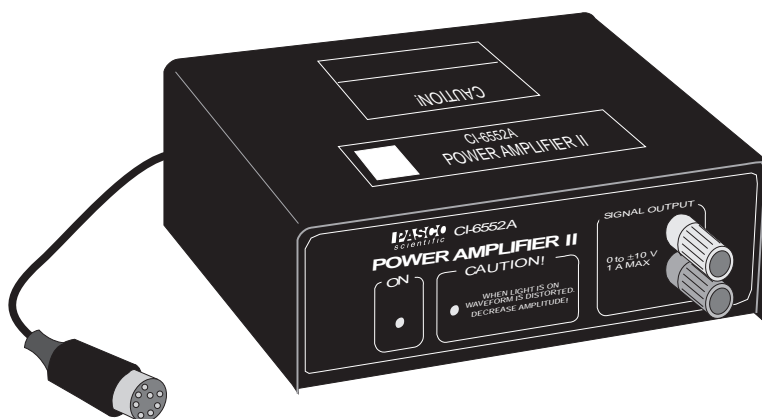
Introduction

The PASCO CI-6552A Power Amplifier II is an accessory to the PASCO Signal Interfaces, Series 6500 and Mac65. It amplifies the output of the computer, allowing it to be used as a controlled DC power source or an AC function generator.

With the Power Amplifier II plugged into one of the analog channels of the Signal Interface, the appropriate software (*Power Amplifier for DOS*, *Power Amplifier for APPLE II*, or *Science Workshop*) can be used to generate the following types of waves (up to ±10V peak at 1A, up to 5,000 Hz):

- sine,
- square,
- triangle, and
- sawtooth.

This means the computer can now be used as an AC signal generator to power external circuits while it monitors its own output current as well as other inputs. The *Science Workshop* software can also generate a DC output.

Filter Select Switch

The CI-6552A Power Amplifier II has a filter select switch which is preset for use with the CI-6560 Signal Interface II (Mac65). The bandwidth at that switch position is about 100KHz, limited by the power amplifier's feedback compensation section and the load. When using the Power Amplifier II with the CI-6510 Signal Interface (Series 6500), the bandwidth needs to be limited to 1.5KHz. To change the switch position push the filter select switch in the back panel slot to the left, as shown in the illustration below.

Switch position for CI-6510 Signal Interface

Switch position for CI-6560 Signal Interface II
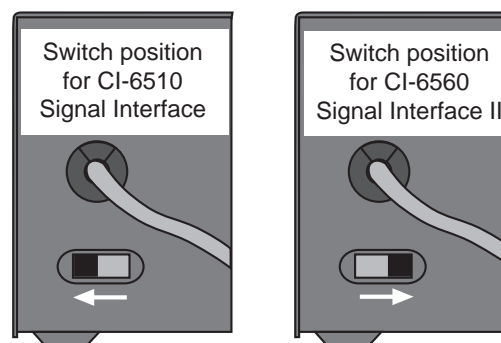
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This instruction edited by Robert Morrison

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Using Power Amplifier II

To install the Power Amplifier II, plug in its power cord and plug the DIN plug into Channel A, B, or C of the appropriate PASCO Signal Interface box (CI-6510 or CI-6560).

> ➤ **NOTE:** Using Power Amplifier II with Series 6500, the *Power Amplifier* program is calibrated for channel C. The Power Amplifier II can also be plugged into Channel A or B but these channels are not automatically calibrated to read the current as is Channel C.

To use the output of the Power Amplifier II, connect the load to the banana jacks on the front of the Power Amplifier II. There is a power switch on the back left hand corner of the Power Amplifier II.

> ➤ **WARNING!** Do not turn on the power switch until a program (*either Power Amplifier, Data Monitor* or *Science Workshop*) has been run and the desired output voltage has been selected.
>
> When the computer is in DOS, the Power Amplifier will output 10 Volts if the power switch is on and this could overload a circuit that might be connected to it. The software controls this voltage: The Data Monitor Program sets the default voltage to zero and the Power Amplifier Program sets the default AC peak voltage to 5 Volts.

When the Power Amplifier II is operating, a green power indicator light on the front panel of the Power Amplifier II will be lit. There is also a red current overload light which comes on whenever the maximum current of 1 A is exceeded. If this warning light is on, the waveform is distorted and you should reduce the output voltage.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer.

Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Equipment Return

Should this product have to be returned to PASCO scientific, for whatever reason, notify PASCO scientific by letter or telephone BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

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CAUTION

**RISK OF ELECTRIC SHOCK
DO NOT OPEN**

CAUTION:
TO PREVENT THE RISK OF ELECTRIC SHOCK, DO NOT REMOVE COVER ON UNIT. NO USER SERVICEABLE PARTS INSIDE. REFER SERVICING TO QUALIFIED SERVICE PERSONNEL.

The lightning flash with arrowhead, within an equilateral triangle, is intended to alert the user of the presence of uninsulated "dangerous voltage" within the product's enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.
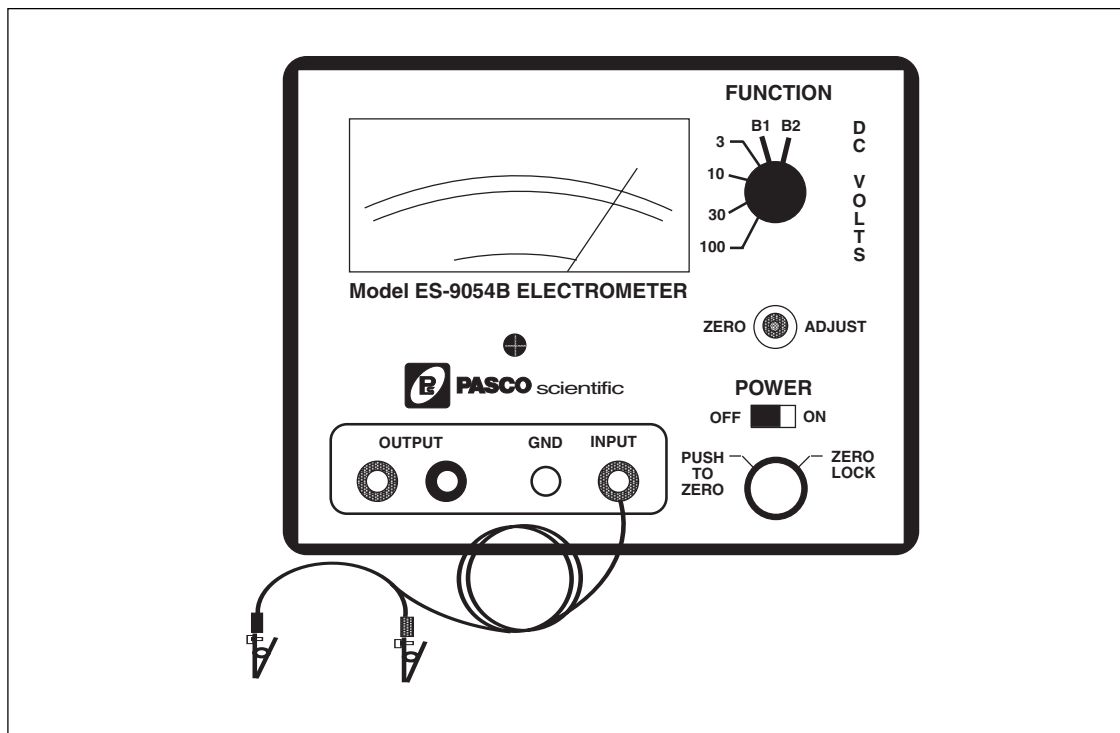
The exclamation point within an equilateral triangle is intended to alert the user of the presence of important operating and maintenance (servicing) instructions in the literature accompanying the appliance.

Instruction Manual and
Experiment Guide for
the PASCO scientific
Model ES-9054B

ELECTROMETER

Model ES-9054B ELECTROMETER

$7.50

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Table of Contents

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or workmanship. The warranty does not cover damage
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③ Make certain that the packing material cannot shift
in the box or become compressed, allowing the
instrument come in contact with the packing carton.

Address:	PASCO scientific
	10101 Foothills Blvd.
	Roseville, CA 95747-7100
Phone:	(916) 786-3800
FAX:	(916) 786-3292
email:	techsupp@pasco.com
web:	www.pasco.com

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Introduction

The Model ES-9054B Electrometer is an infinite impedance (10^{14} ý) voltmeter that can be used for direct measurements of voltage, and indirect measurements of current and charge. Because of its high impedance, it is especially suited for measuring charge in electrostatic experiments. It has a sensitivity nearly 1,000 times that of a standard, gold-leaf electroscope, it has a center-zero meter that directly indicates charge polarity, and it measures charges as low as 10^{-11} coulombs.

With these features, you'll find that your electrostatics demonstrations and labs are easier to perform and, with quantitative data, are more informative as well.

The electrometer is battery powered by two 9 volt batteries, and comes complete with the batteries and a shielded test lead. Instructions for inserting the batteries are at the end of this manual.

Operation

The controls on the front panel of the electrometer are explained in Figure 1. Whether you're using the electrometer to measure voltage, current, or charge, the following procedure should be followed each time you turn on the electrometer. More information on making accurate measurements is given in the sections that follow.

➤**IMPORTANT:**
① **Never** use the Electrometer for measuring potentials in excess of 100 volts.

② **Never** connect the electrometer to an electrostatic generator such as a Van de Graff generator or a Wimshurst machine.

③ **Never** touch the input leads until you have grounded yourself to an earth ground. A person walking across a rug on a cool, dry day can easily pick up a potential of several thousand volts.
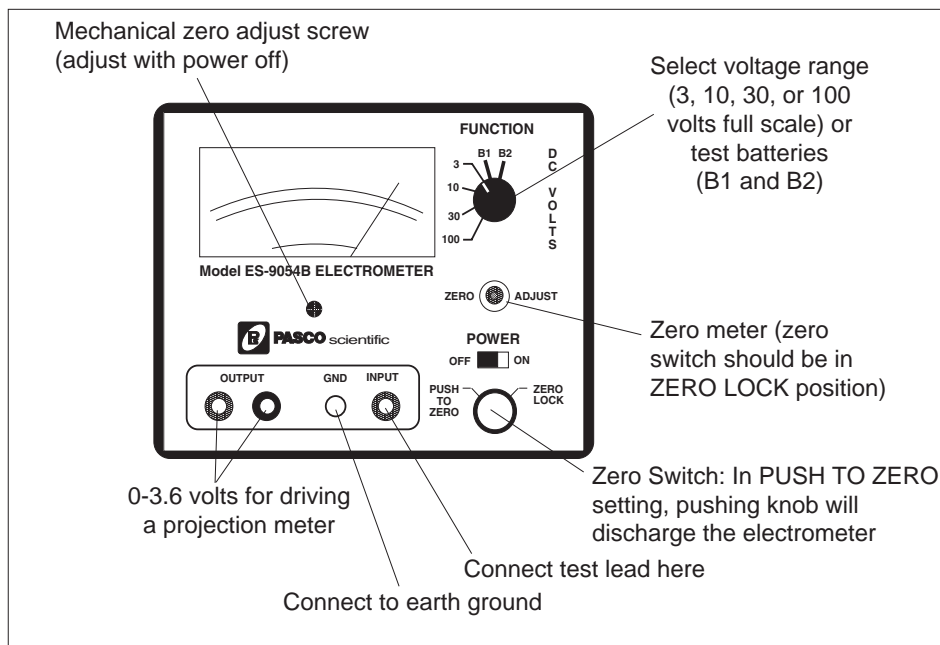
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Figure 1 Front Panel Controls

Setup

① Before turning on the electrometer, check that the meter reads zero. If not, turn the Mechanical Zero Adjust screw, located just below the meter face, until it does.

② Slide the POWER switch to the ON position.

③ Check the batteries:

  a. Turn the FUNCTION switch to B1. The meter pointer should read to the left of the B1 line at the bottom of the meter face. If the pointer falls within the area labeled B1, see the battery replacement section at the end of this manual.

  b. Turn the FUNCTION switch to B2. The meter pointer should read to the right of the B2 line at the bottom of the meter face. If the pointer falls within the area labeled B2, see the battery replacement section at the end of this manual.

④ Zero the meter:

  a. Turn the FUNCTION switch to 3.

  b. Turn the Zero Switch to the ZERO LOCK setting.

  c. Adjust the ZERO ADJUST knob so the meter reads zero volts.

⑤ Turn the Zero Switch to the PUSH TO ZERO setting.

⑥ Connect the test lead to the INPUT connector of the electrometer.

⑦ Connect the GND post of the electrometer to an earth ground.

You're now ready to use the electrometer to measure

charge or voltage. Set the FUNCTION switch to the desired voltage range. The range setting refers to the voltage input required to produce a full-scale meter deflection (e.g., a setting of 30 means that a full scale meter deflection indicates a voltage of 30 volts).

➤ **Important Points for General Operation:**

① Between measurements, always press the Zero Switch to discharge all current from the electrometer. (The Zero Switch must be in the PUSH TO ZERO setting.) Shorting the test leads together is insufficient. There may still be stray charges within the electrometer circuitry.

② When adjusting the zero point of the electrometer, always turn the Zero Switch to the ZERO LOCK position.

③ For good results, it is essential that the electrometer be connected to an earth ground (a water pipe or the ground wire from a 120 VAC socket). Only an earth ground provides a sufficient drain for excess charges that may build up during an experiment. It is also helpful if the experimenter is grounded. Just touch one hand to a good earth ground while, or just before, making measurements.

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Measuring Charge

Charge measurement with the electrometer is indirect, but simple. It is based on the relationship $Q = CV$, where
Q and V are the charge and voltage across a capacitor and C is the capacitance. The electrometer can be thought of as an infinite impedance voltmeter in parallel with a capacitor, as shown in Figure 2. The capacitor represents the internal capacitance of the
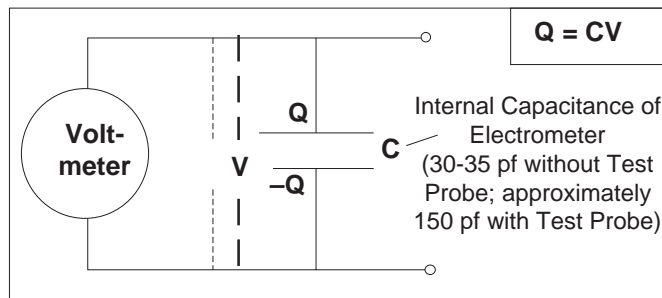

$$Q = CV$$

Volt-meter   V   Q   −Q   C   Internal Capacitance of Electrometer (30-35 pf without Test Probe; approximately 150 pf with Test Probe)

Figure 2 Ideal Schematic of the Electrometer

electrometer, plus the capacitance of the leads.

When a charge is placed across the Electrometer leads, a voltage V will read on the meter. If the value C is known, the value of the charge can be calculated as $Q = CV$. However, when you touch the Electrometer leads to another object to test a charge, the capacitance may change. If the object adds significant capacitance, the situation becomes as shown in Figure 3. The new capacitance $(C + C_{ext})$ must be determined to accurately calculate the charge from the measured voltage.

$$Q + Q' = (C + C_{ext}) V$$

Volt-meter   V   Q   −Q   C   Q'   −Q' C_{ext} Capacitance of object connected to the Electrometer
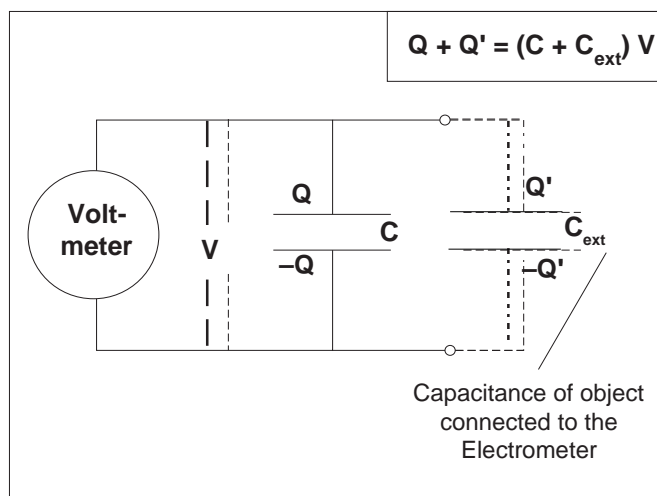
Figure 3 Change in Capacitance Due to Charged Object

Measuring Charge by Induction

Under most conditions, the best way to measure charge is by induction, using a proof plane and a Faraday ice pail such as those included with PASCO's Demonstration Electrostatics System. The proof plane is simply a small conductive disk on an insulating handle. You can make your own ice pail by mounting a conductive cylinder on an insulating support, and placing a larger conductive cylinder around it as a shield. Connect the test lead of the electrometer probe to the inside cylinder, and connect the ground lead to the outside cylinder (see Figure 4).
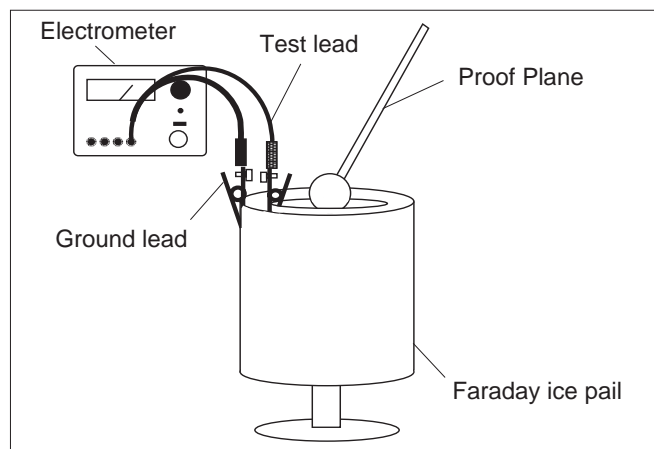

Electrometer   Test lead   Proof Plane   Ground lead   Faraday ice pail

Figure 4 Using a Faraday Ice Pail

To sample the charge distribution on a charged object, simply touch it with the proof plane, then place the proof plane inside the inner cylinder of the ice pail, without touching the cylinder. A charge is induced on the inside cylinder that is equal but opposite to that on the proof plane. You can now read the voltage on the electrometer. By always using the proof plane and the ice pail, the capacitance will be the same for all your measurements and the charge on the proof plane will always be proportional to the voltage reading of the electrometer. However, in experiments for which you want to know the absolute charge on the proof plane, you need to know the total capacitance of the electrometer, plus the test probe, plus the ice pail with the proof plane inside it. Fortunately, this is easily measured, as described below. Once you know the capacitance, you can calculate the absolute charge for any measurement as $\mathbf{Q = CV}$.

To measure the total capacitance:

① Turn on the Electrometer and zero the meter. Clip the test lead of the probe to the inside cylinder of your ice pail and the ground lead to the outside cylinder (see Figure 4).

② Use a DC power supply or a statically charged object to charge your proof plane.

③ Place the proof plane inside the inner cylinder of the ice pail and adjust the FUNCTION switch to get a meter reading near full scale. (For convenience, you may want to touch the proof plane to the inside of the ice pail and then remove the proof plane. The effect on the voltage reading should be negligible.) Record the voltage as V_e. Do **not** discharge the Electrometer.

④ Take a capacitor of known capacitance, C_k. Ground the leads of the capacitor to be sure it is fully discharged, then connect the capacitor between the inner and outer cylinder of the ice pail. With the proof plane still inside the ice pail, record the meter reading as V_k.

⑤ The capacitance of the Electrometer, C_e, can now be calculated as:

$$C_e = C_k V_k / (V_e - V_k).$$

➤ **EXPLANATION:** This measurement is shown schematically in Figure 3. First the Electometer is charged with an unknown charge Q, that must satisfy the equation $Q = C_e V_e$, where C_e is the total capacitance of the system and V_e is the Electrometer reading. Then the second capacitor is connected in parallel with the capacitance of the Electrometer. The total capacitance is now $C_e + C_k$. The charge Q has not changed, but now satisfies the equation $Q = (C_e + C_k)V_k$, where V_k is the new Electrometer reading. Combining the two equations gives, $C_e V_e = (C_e + C_k)V_k$, or $C_e = C_k V_k / (V_e - V_k)$.

If you want to use the Electrometer with a different set of test leads, or a different ice pail, or even a different proof plane, the capacitance may be different, and you will need to repeat the above procedure to measure the new capacitance.

➤ **NOTE:** The capacitance of the Electrometer is 30-35 pf. With the test probe, the total capacitance is approximately 150 pf. For best results, measure the total capacitance.

Measuring Charge by Contact

Charges can also be measured by contact. You'll find, for example, that if you touch the charged proof plane to the

inside cylinder of the ice pail, the Electrometer reading will generally remain relatively unchanged. This is because the total capacitance is only negligibly affected by the proof plane. This may not always be the case, however.

In general, contact measurements can be carried out in much the same way as inductive measurements using the ice pail. Touch the object with the test probe, record the voltage V, and use $Q = CV$ to calculate the charge. However, if you suspect the object for which you are measuring the charge appreciably affects the total capacitance of the system, you will need to remeasure the capacitance as described above.

Measuring Voltage

Voltage can be measured as with any voltmeter. Connect the leads to the circuit, set the range (3, 10, 30, or 100 volts full scale), and read the voltage on the meter.

Measuring Current

The Electrometer can be used for indirect current measurements in many situations, though it is no substitute for a good ammeter. Connect the Electrometer leads across a known resistance in the circuit and measure the voltage. Use Ohm's law (Voltage = Current x Resistance) to determine the current. The effect of the Electrometer on the circuit will be negligible in most circuits due to its exceedingly high input impedance. However, the voltage drop across the resistor must be within the voltage range of the Electrometer.

If it is not convenient to hook the Electrometer across a known resistance in the circuit, a precision resistor can be connected between the input leads of the Electrometer. The circuit can then be broken, as for connection to a standard ammeter, and connected in series with the precision resistor. Again, measure the voltage across this resistor and calculate the current. (The problem with this technique is that the resistance must be high enough so the voltage drop is easily measured, but low enough so it doesn't significantly affect the current through the circuit.)

Using a Projection Meter

The OUTPUT connectors on the ES-9054B Electrometer provide an output signal for driving a projection meter, oscilloscope, or other monitoring device. The output is proportional to meter deflection (within 10%) with a ± 3.6 VDC output corresponding to a full scale deflection. (The OUTPUT voltage depends only on meter deflection. It is independent of the range setting of the FUNCTION switch.)

PASCO's Model ES-9065 Projection Meter can be used with an overhead projector to display the Electrometer readings for the whole class. The Projection Meter connects directly to the OUTPUT jacks, red to red and black to black.

To calibrate the Projection Meter:

① Set the FUNCTION switch to 3, and the Zero Switch to ZERO LOCK.

② Turn the ZERO ADJUST knob until the meter on the Electrometer reads as close to full scale as possible (either postive or negative).

③ Adjust the CALIBRATE knob on the Projection Meter so that the Projection Meter reads the same as the Electrometer.

④ Turn the ZERO ADJUST knob until the Electrometer and the Projection Meter read zero.

Maintenance

Checking Out Your Electrometer

① Follow the setup instructions on pages 2-3 of this manual to check the batteries and zero the Electrometer. If the batteries are low, see "Battery Installation." If the meter cannot be zeroed, see "MOS-FET Replacement."

② **Calibration Test:** Set the FUNCTION switch to 30 and connect the input to an accurate 30 VDC source. If the meter does not read 30 volts ±5%, see "Calibration."

③ **Input Impedance Test:** Set the FUNCTION switch to 30 and connect the input to a 30 VDC source. Disconnect the input cable at the front panel input connector. Record the meter reading and the time. If the input impedance is sufficient, it will take 15 minutes or longer for the meter reading to decrease to 30% of its initial value. If the input impedance is low, see "Repairs."

④ **Zero Drift Test:** With the meter zeroed, short the leads of the input cable together. Turn the Zero Switch to PUSH TO ZERO and depress the knob, then release it. The meter should read zero volts and should drift by no more than 75 mV/minute. At any time, depressing the Zero Switch should bring the meter immediately back to zero. If the zero drift is excessive, see "Repairs."

> ➤ **IMPORTANT:** A zero drift test is best performed after the Electometer has been left unused with the Zero Switch in the ZERO LOCK position for at least four hours. During use with high voltages, or during battery replacement or other maintenance, charges may be produced on the insulators of the input circuit. The bleeding off of these charges may appear as excessive zero drift.

> ➤ **CAUTION:** Whenever you open your Electrometer, do not touch any of the components on the printed circuit board other than the battery holders or the trim potentiometers. The printed circuit contains the high impedance MOS-FET input which can be damaged just by touching the wrong lead.
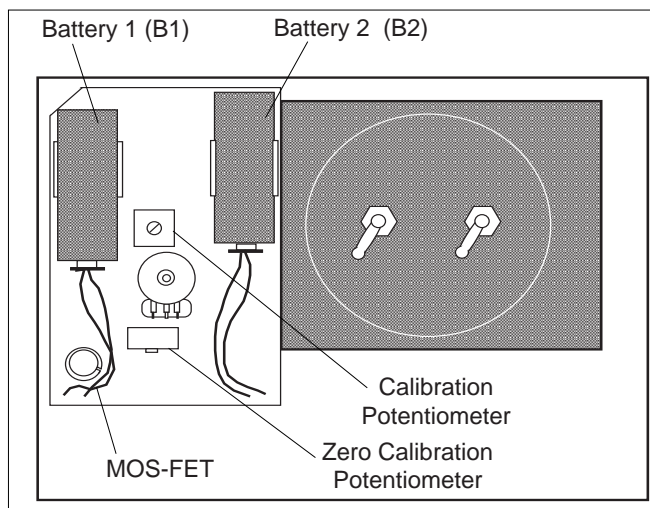

Figure 5 Inside the Electrometer

Battery Installation

To install or replace the batteries, remove the four screws that fasten the front panel to the case, then gently lift the front panel out of the case. Install the batteries as shown in Figure 5. When removing and installing the batteries, be careful not to bend the battery clips or pull the battery wires out of the circuit board. Place the new batteries in the clips with the positive terminal closest to the printed circuit board. Before replacing the front panel, test that the batteries are good and the connections are secure by flipping the FUNCTION switch first to B1 and then to B2. The meter pointer should be deflected out beyond the areas labeled B1 and B2, respectively, at the bottom of the meter face. Replace the front panel.

Calibration

① Remove the four screws that fasten the front panel to the case, then gently lift the front panel out of the case.

② Turn the POWER switch to ON.

③ Set the FUNCTION switch to 3.

④ Flip the Zero Switch to ZERO LOCK. With the ⁻zero adjust knob midway between its extreme cw and ccw positions, adjust the Zero Calibration Potentiometer to zero the meter.

⑤ Set the Function Switch to 30, zero the meter using the zero adjust knob on the front panel, then connect the INPUT of the Electrometer to a known, accurate 30 VDC source.

⑥ Flip the Zero Switch to the PUSH TO ZERO setting.

⑦ Adjust the Calibration Potentiometer (see Figure 5) until the meter reads 30 volts.

⑧ Press the Zero Switch, then release it. The meter should still read 30 volts. If it doesn't, readjust the Calibration Potentiometer until it does.

MOS-FET Replacement

If the meter can't be zeroed using the ZERO ADJUST knob with the Zero Switch set to ZERO LOCK, the MOS-FET has probably failed. (MOS-FET is an acronym for Metal Oxide Semiconductor-Field Effect Transistor). You can order a replacement from PASCO scientific (Part # 422-001). When ordering a replacement part, be sure to include the model number of the Electrometer.

To replace the MOS-FET:

① Turn the Electrometer off.

② Remove the four corner screws that fasten the front panel to the case, and gently lift out the front panel.

③ Gently pull the MOS-FET out of its socket (see Figure 5). Avoid yanking or twisting it, as this may damage the transistor socket.

④ The replacement MOS-FET will probably come in an anti-static bag or may be wrapped in aluminum foil. The leads will be protected by a thin ring or spring that is wound around the leads near where they protrude from the base of the transistor. Gently remove the MOS-FET from the bag or foil, but do not remove the thin wire ring that is around the leads. Leave this wire ring in place until after the MOS-FET is seated in the socket.

⑤ The MOS-FET has a small metal tab protruding from one side (see Figure 6). The lead directly below the tab (as seen from the top side of the transistor) is lead number 8. Count back to lead number 5, as shown, and gently bend the lead up.

⑥ Insert the leads of the MOS-FET, except for lead 5, into the socket so that the metal tab lines up with the notch on the side of the socket as shown in the figure.

⑦ Insert lead number 5 into the socket that is connected to the adjacent binding post. This may be done by inserting the lead through the slot in the end of the socket, and then bending the end of the lead back and crimping it tightly. Now gently pull off the thin ring of wire that is wound around the leads. This may require thin nose pliers or "tweezers".

⑧ Replace the cover.

Repair

Should your Electrometer have problems that are not covered in the preceding sections, we strongly suggest you return it to PASCO scientific for repair.
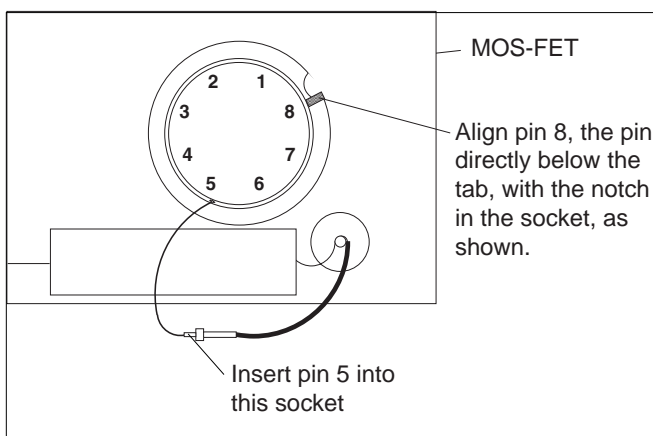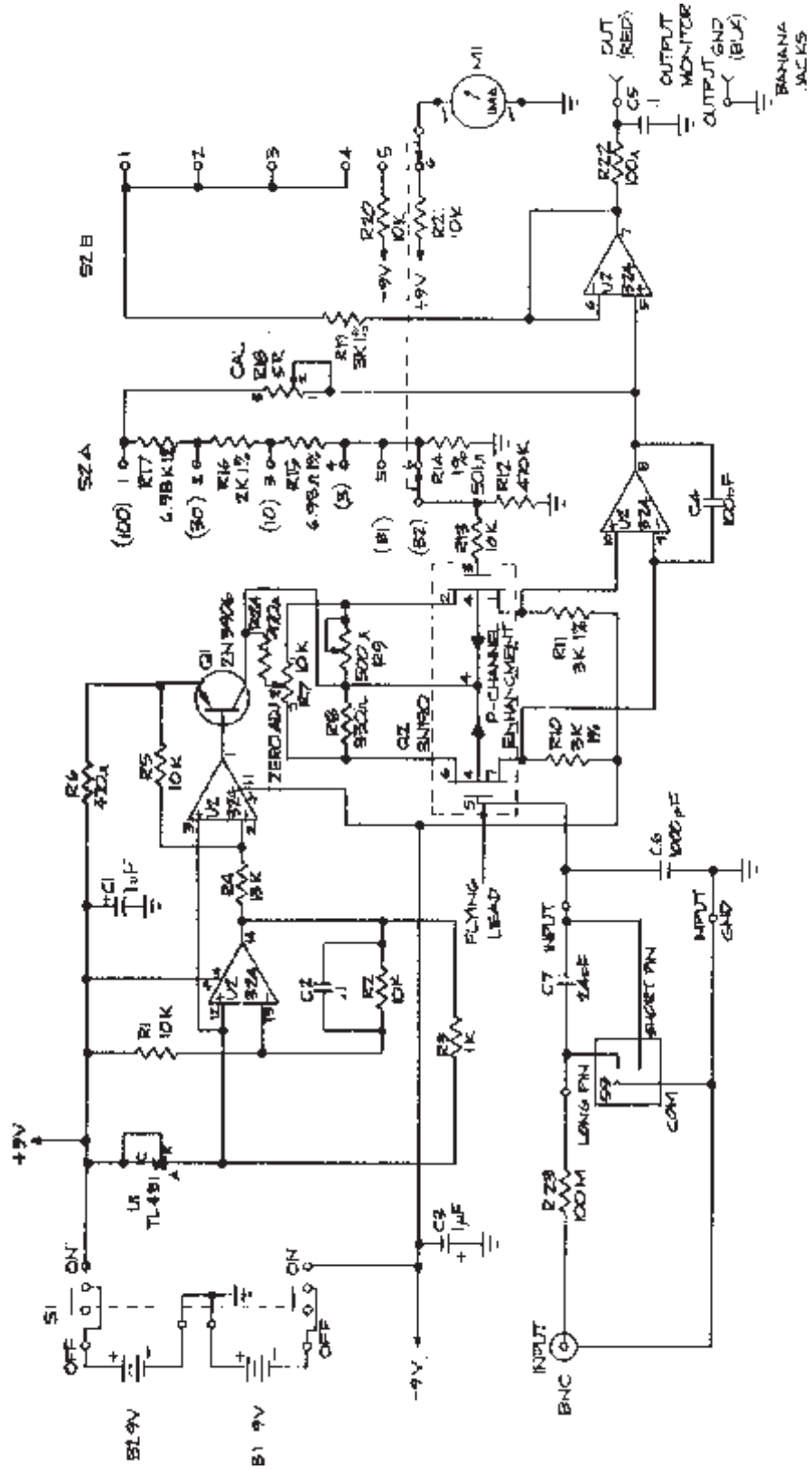

Figure 6 MOS-FET Installation

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SCHEMATIC
Model ES-9054B Electrometer
(Drawing #956-02859)

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Parts List

Reference	Description	PASCO Part #
R1,2,5,13, 20,21	Resistor, 10 kΩ, 1/4 W, 5%	113-103
R3	Resistor, 1 kΩ, 1/4 W, 5%	113-102
R4	Resistor, 13 kΩ, 1/4 W, 5%, C.C.	113-133
R6,24	Resistor, 470 Ω, 1/4 W, 5%	113-471
R7	Potentiometer, 10 kΩ, 1/4 W, 30%	140-006
R8	Resistor, 330 Ω, 1/4 W, 5%	113-331
R9	Trimpot, 500 Ω	142-031
R10,11,19	Resistor, 3.01 kΩ, 1/8 W, 1%, MF	124-007
R12	Resistor, 470 kΩ, 1/4 W, 5%	113-474
R14	Resistor, 301 Ω, 1/8 W, 1%	124-004
R15	Resistor, 698 Ω, 1/8 W, 1%, MF	124-005
R16	Resistor, 2 kΩ, 1/8 W, 1%, MF	124-006
R17	Resistor, 6.98 kΩ, 6.81 kΩ, 1/8 W, 1%	124-008
R18	Potentiometer, 5 kΩ, 10%	142-018
R22	Resistor, 100 Ω, 1/4 W, 5%	113-101
R23	Resistor, 100 MΩ, 1/2 W, 20%	150-007
C1,3	Capacitor, 1.0 μf, 10%, 35 V, Axial	220-004
C2,5	Capacitor, 0.1 μf, 25 V, Monolithic	210-018
C4	Capacitor, 100 pf	210-014
C6	Capacitor, 0.001μf, 5%, 600 V	216-013
C7	Capacitor, 24 pf, 5%, 600 V	216-003
Q1	Transitor—2N3906	420-003
Q2	Transistor—MOS-FET 3N190	422-001
U1	IC—TL431 Voltage Regulator	430-083
U2	IC—LM324N	430-027
S1	Switch—Slide, 2 Pole, 2 Position	512-007
S2	Switch—2 Pole, 6 Position, Rotary	510-019
M1	Meter	525-00682

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@pasco.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is with the PASCO apparatus, note:
  - Title and model number (usually listed on the label);

  - Approximate age of apparatus;

  - A detailed description of the problem/sequence of events (in case you can't call PASCO right away, you won't lose valuable data);

  - If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:
  - Part number and revision (listed by month and year on the front cover);

  - Have the manual at hand to discuss your questions.

**Instruction Sheet
for the PASCO
Model ES-9049A**

POWER SUPPLY

Introduction
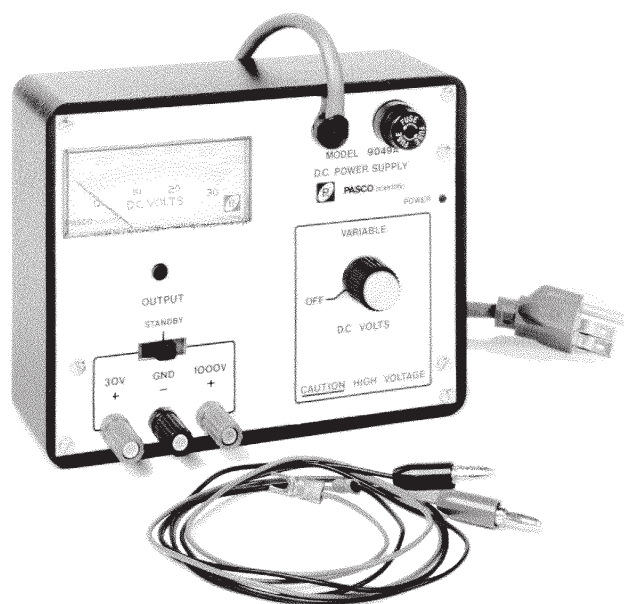
The PASCO Model ES-9049A Power Supply is a two range supply providing all the necessary potentials for PASCO electrostatics equipment.

Operating Instructions

Turn the unit ON by turning the VARIABLE control knob clockwise.

Select the 30 VDC or 1000 VDC range using the OUT-PUT switch. The center position of the switch (STANDBY) will produce a zero output at the terminals, regardless of the voltage control settings.

When using the 30 VDC range use the red and black binding posts. The black binding post is connected to the third prong (ground) on the power cord.

When using the 1000 VDC range use the black and green binding posts. When the green binding post is used there is a 100 MΩ resistor in series with the output. This eliminates the hazard of shock if the green terminal is accidentally touched. However, if one attempts to measure the output of this terminal with a meter having less than several hundred MΩ of input impedance the meter on the ES-9049A and the measuring meter will not read the same. This is due to the voltage drop across the 100 MΩ resistor produced by the current needed to drive the meter.

Voltage output is varied by the voltage control knob.

Specifications:

① **Ranges:**

    a) 1000 VDC, less than 2% ripple peak-to-peak, un-regulated (maximum short circuit current less than 0.01 mA)

    b) 30 VDC at 20 mA, 0.3% ripple peak-to-peak, line and load regulation to within 1%.

② **Meter:** Two scale, +/- 3% of full-scale accuracy.

③ **Power:**

    a) 110-130 VDC, 60 Hz

    b) 220/240 VDC, 50 Hz

④ **Fuse:**

    a) 0.2 A, Slo-Blo. (110-130 VDC)

    b) 0.1 A, Slo-Blo. (220/240 VDC)

⑤ **Dimensions:** 17.5 x 13.5 x 6 cm

CAUTION

**RISK OF ELECTRIC SHOCK
DO NOT OPEN**

CAUTION:
TO PREVENT THE RISK OF ELECTRIC SHOCK, DO NOT REMOVE COVER ON UNIT. NO USER SERVICE-ABLE PARTS INSIDE. REFER SERVICING TO QUALI-FIED SERVICE PERSONNEL.

The lightning flash with arrowhead, within an equilateral triangle, is intended to alert the user of the presence of uninsulated "dangerous voltage" within the product's enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.

The exclamation point within an equilateral triangle is intended to alert the user of the presence of important operating and maintenance (servicing) instructions in the literature accompanying the appliance.

Maintenance

There is no routine maintenance required for the ES-9049A Power Supply. However, power line surges can blow the protective fuse without damaging the instrument. Therefore, should the instrument fail to operate and the fuse is blown, replace it with a new fuse of the appropriate value. If the instrument subsequently works properly, no further action is necessary. If the fuse blows again (it may take 15 seconds), refer to the 'Repairs' section in this manual.

Repairs

Should the ES-9049A Power Supply require repair, it is strongly recommended that the unit be returned to PASCO scientific. Because PASCO is thoroughly familiar with the instrument and maintains a complete stock of replacement parts, repairs can be made quickly and at low cost.

If field repair is desired, a schematic and parts list are included in the following section. A brief list of malfunctions and their probable causes are also given.

Troubleshooting Tips

① No output on any range:

  Fuse blown

② Low output on 1000 VDC range:

  Defective capacitor C2, C3, C4, or C5.

③ No output on 30 VDC range but other range is all right:

  Defective zener diode CR5 or power transistor Q1.

④ Proper output, but no meter readings:

  Defective meter M1.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Equipment Return

Should this product have to be returned to PASCO scientific, for whatever reason, notify PASCO scientific by letter or phone BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

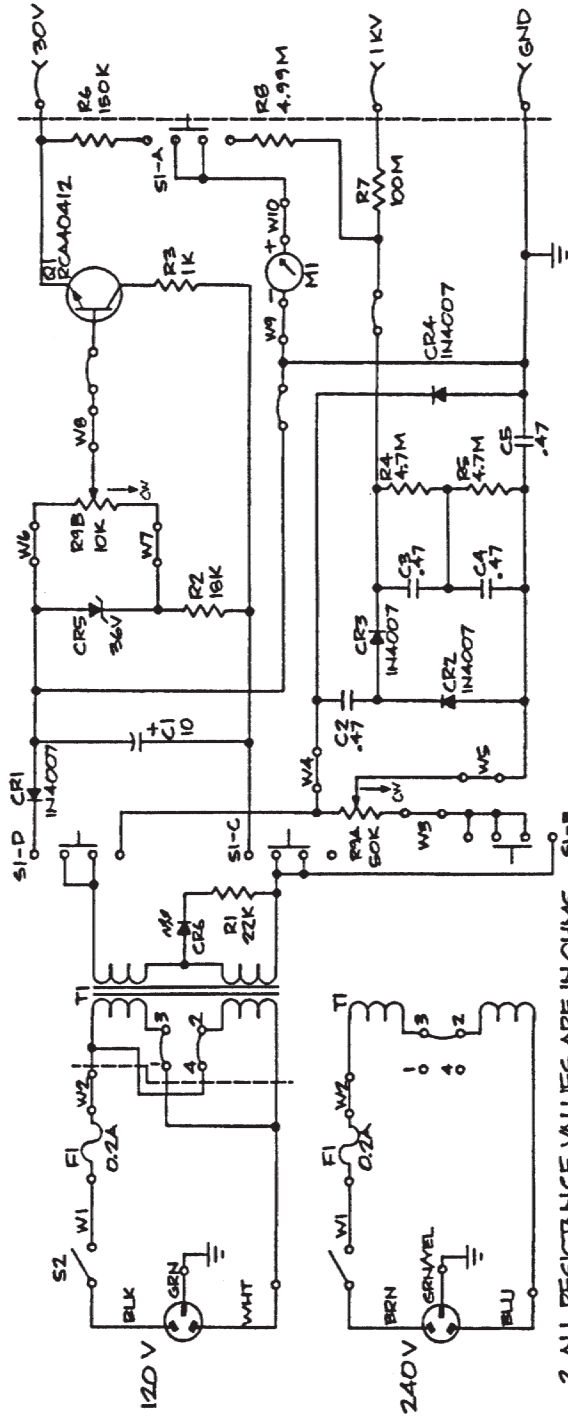> ➤NOTE: NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing.

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PARTS LIST

Specification	Pasco part no.	Reference
Resistors:		
22K, 1/4W, 5%	113-223	R1
18K, 2W, 5%	110-183	R2
1K, 2W, 5%	110-102	R3
4.7M, 1/4W, 5%	113-475	R4, R5
150K, 1/2W, 1%	122-064	R6
100M, 1/2W, 5%	150-006	R7
4.99M, 1/2W, 1%	150-015	R8
POT, Two Section	140-032	R9A/B*, S2*
Capacitors:		
10mF, 450V, Electrolytic	222-003	C1
.47mF, 400V, Mylar	214-007	C2-C5
Transformer:		
Power, 115/230-2X115V	322-009	T1
Diodes/Semiconductors:		
1N4007, 1000PIV, 1A Silicon Rect	410-002	CR1-CR4
1N4753A, 36V, 1W, 5% Zener	412-004	CR5
LED Red	527-001	CR6
Power Transistor RCA40412 NPN	420-005	Q1
Switch:		
Slide, 4Pole, 3Position	512-016	S1
Fuse/Meter:		
.2A SLO-BLO (110-130VDC)	530-001	F1
.1A SLO-BLO (220/240VDC)	530-006	F1
Meter	525-00804	M1
Mechanical:		
Bakelite Case, Black	650-01462	
Front Panel	648-00803	
Control Knob	620-002	
Binding Post, Red	517-013	
Binding Post, Black	517-014	
Binding Post, Green	517-015	
Fuse Holder	520-003	
Power Cord, Domestic	516-001	
Power Cord, European	516-003	
Dissipater	624-001	

➤NOTE: R9A/B and S2 are concentrically mounted on the Variable Control shaft and comprise a single unit.

SCHEMATIC

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Instruction Manual and Experiment Guide for the PASCO scientific Model EM-8622

BASIC ELECTRICITY

$10.00

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Credits

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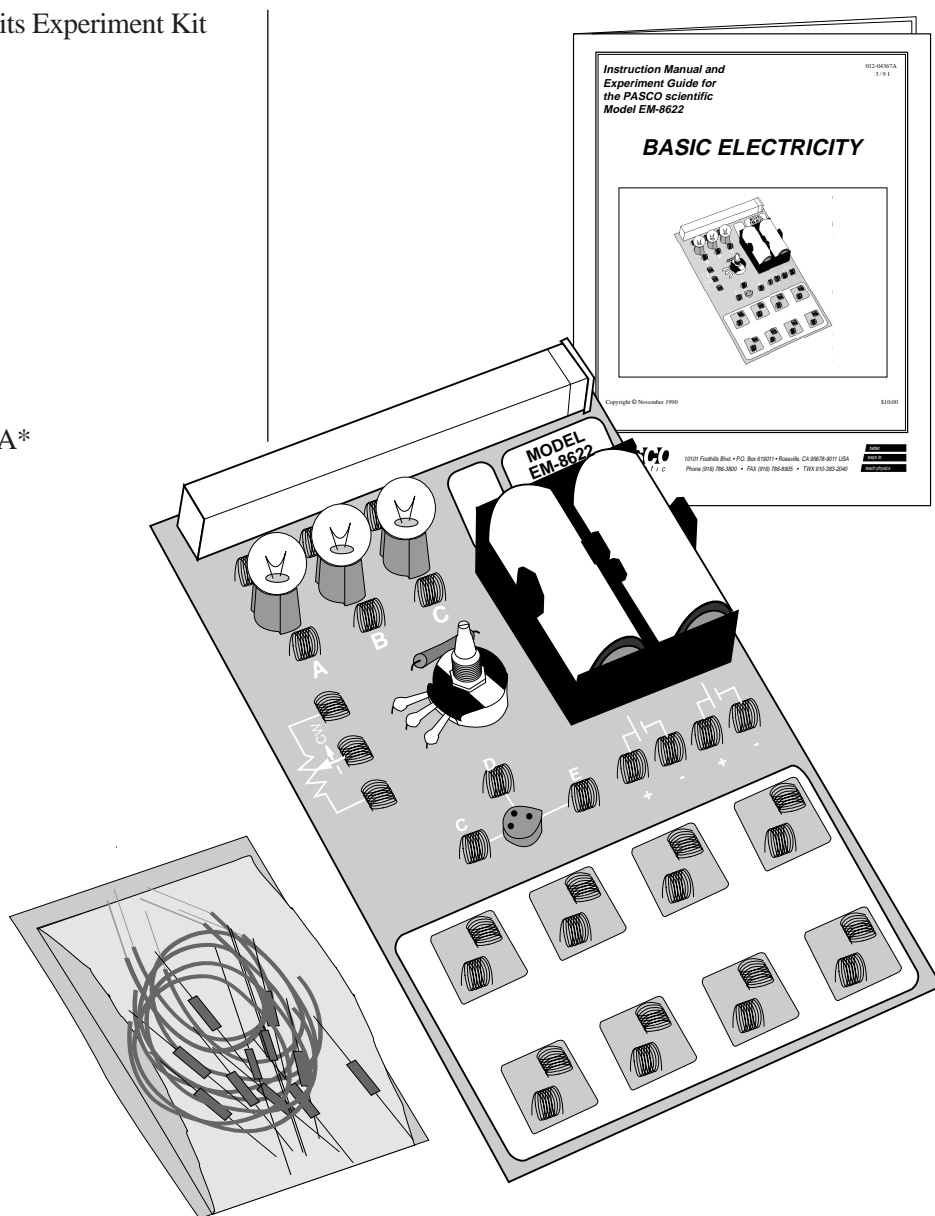**PASCO** *scientific*

Introduction

The PASCO Circuits Experiment Board is designed to implement a large variety of basic electrical circuits for experimentation. The Circuits Experiment Board can be used for experiments beginning with a simple complete circuit and continuing on to a study of Kirchhoff's Laws and characteristics of diodes and transistors. A labeled pictorial diagram of the Experiment Board appears in Figure 1.2 of Experiment 1.

Equipment

The PASCO Model EM-8622 Circuits Experiment Kit includes the following materials:

(2) Circuits Experiment Boards,

    (1) Resistor— 3.3 Ω, 2W, 5%

    (1) Potentiometer— 25 Ω, 2W

    (1) Transistor Socket

    (32) Springs

    (1) Battery Holder

    (3) Light Sockets

    (3) #14 Light Bulbs – 2.5 V, 0.3 A*

    (1) Storage Tube

(1) Component Bag

    Resistors

        (2) 10 Ω— 1 watt

        (3) 100 Ω— 1/2 watt

        (8) 330 Ω— 1/2 watt

        (3) 560 Ω— 1/2 watt

        (3) 1000 Ω— 1/2 watt

        (2) 100 K Ω— 1/2 watt

        (2) 220 K Ω— 1/2 watt

    (2) Diodes 1N-4007

    (2) Transistors 2N-3904

    Capacitors

        (2) 100 μF— 16 volts

        (2) 330 μF— 16 volts

    Wire Leads— 22 ga.

(1) Experiment Manual

Instruction Manual and Experiment Guide for the PASCO scientific Model EM-8622

012-04367A 3 / 9 1

BASIC ELECTRICITY

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MODEL EM-8622

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* **NOTE:** Due to manufacturer's tolerances, wattage may vary by 15-30% from bulb to bulb.

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Getting Started

① Open the zip-lock bag containing the resistors and other components. Distribute the following resistors and wires to each of the boards, storing them in the plastic holder at the top of the board:

    (3) 5" Wire Leads (12.7 cm)

    (4) 10" Wire Leads (25.4 cm)

    (1) 100 Ω Resistor (brown, black, brown, gold)

    (3) 330 Ω Resistors (orange, orange, brown, gold)

    (1) 560 Ω Resistor (green, blue, brown, gold)

    (1) 1000 Ω Resistor (brown, black, red, gold)

    Store the remainder of the components in the zip-lock bag until needed in future experiments.

② Students will need to use the same resistors, same batteries, etc. from one experiment to another, particularly during experiments 4 to 6. Labeling of the boards and your meters will enable students to more easily have continuity in their work. A pad has been included on the board for purposes of labeling individual boards. Use of a removable label or using a permanent marker are two alternatives.

The Experiments

The experiments written up in this manual are developmental, starting from an introduction to the Circuits Experiment Board and complete circuits, through series and parallel circuits, ultimately resulting in diode and transistor characteristics. These experiments can be used in combination with existing labs that the teacher employs, or may be used as a complete lab unit.

Experiment 1   Circuits Experiment Board

Experiment 2   Lights in Circuits

Experiment 3   Ohm's Law

Experiment 4   Resistances in Circuits

Experiment 5   Voltages in Circuits

Experiment 6   Currents in Circuits

Experiment 7   Kirchhoff's Rules

Experiment 8   Capacitors in Circuits

Experiment 9   Diode Characteristics

Experiment 10   Transistor Characteristics

Additional Equipment needed:

Experiments 3-10   Digital Multimeter, VOM or VTVM (See discussion on page 3)

Experiments 8-10   The Meter needs at least 10^6 Ω input impedance

Experiment 8   A timing device is needed, 0.1 second resolution.

Experiment 9   A.C. Power Supply and an Oscilloscope (optional)

Comments on Meters

VOM:

The Volt-Ohm-Meter or VOM is a multiple scale, multiple function meter (such as the PASCO SB-9623 Analog Multimeter), typically measuring voltage and resistance, and often current, too. These usually have a meter movement, and may select different functions and scales by means of a rotating switch on the front of the unit.

Advantages: VOM's may exist in your laboratory and thus be readily accessible. A single meter may be used to make a variety of measurements rather than needing several meters.

Disadvantages: VOM's may be difficult for beginning students to learn to read, having multiple scales corresponding to different settings. VOM's are powered by batteries for their resistance function, and thus must be checked to insure the batteries are working well. Typically, VOM's may have input resistances of 30,000 Ω on the lowest voltage range, the range that is most often used in these experiments. For resistances in excess of 1,000 Ω, this low meter resistance affects circuit operation during the taking of readings, and thus is not usable for the capacitor, diode and transistor labs.

DMM:

The Digital Multimeter or DMM is a multiple scale, multiple function meter (such as the PASCO SB-9624 Basic Digital Multimeter or the SE-9589 General Purpose DMM), typically measuring voltage and resistance, and often current, too. These have a digital readout, often with an LCD (Liquid Crystal Display). Different functions and scales are selected with either a rotating switch or with a series of push-button switches.

Advantages: DMM's are easily read, and with their typically high input impedances ($>10^6$ Ω) give good results for circuits having high resistance. Students learn to read DMM's quickly and make fewer errors reading values. Reasonable quality DMM's can be purchased for $60 or less. PASCO strongly recommends the use of DMM's.

Disadvantages: DMM's also require the use of a battery, although the lifetime of an alkaline battery in a DMM is quite long. The battery is used on all scales and functions. Most DMM's give the maximum reading on the selector (i.e., under voltage, "2" means 2-volt maximum, actually 1.99 volt maximum). This may be confusing to some students.

VTVM:

The Vacuum Tube Voltmeter or VTVM is a multiple scale, multiple function meter, typically measuring voltage and resistance. They do not usually measure current. The meter is an analog one, with a variety of scales, selected with a rotating switch on the front of the meter.

Advantages: VTVM's have high input resistances, on the order of 10^6 Ω or greater. By measuring the voltage across a known resistance, current can be measured with a VTVM.

Disadvantages: VTVM's have multiple scales. Students need practice to avoid the mistake of reading the incorrect one. An internal battery provides the current for measuring resistance, and needs to be replaced from time to time. Grounding problems can occur when using more than one VTVM to make multiple measurements in the same circuit.

Panelmeters:

Individual meters, frequently obtained from scientific supply houses, are available in the form of voltmeters, ammeters, and galvanometers (such as PASCO's SE-9748 Voltmeter 5 V, 15 V , SE-9746 Ammeter 1 A, 5 A and SE-9749 Galvanometer ± 35 mV). In some models, multiple scales are also available.

Advantages: Meters can be used which have the specific range required in a specific experiment. This helps to overcome student errors in reading.

Disadvantages: Using individual meters leads to errors in choosing the correct one. With limited ranges, students may find themselves needing to use another range and not have a meter of that range available. Many of the individual meters have low input impedances (voltmeters) and large internal resistances (ammeters). Ohmmeters are almost nonexistent in individual form.

Light Bulbs

The #14 bulbs are nominally rated at 2.5 V and 0.3 A. However, due to relatively large variations allowed by the manufacturer, the wattage of the bulbs may vary by 15 to 30%. Therefore, supposedly "identical" bulbs may not shine with equal brightness in simple circuits.

Notes on the Circuits Experiment Board

The springs are securely soldered to the board and serve as a convenient method for connecting wires, resistors and other components. Some of the springs are connected electrically to devices like the potentiometer and the D-cells. In the large Experimental Area, the springs are connected in pairs, oriented perpendicular to each other. This facilitates the connection of various types of circuits.

If a spring is too loose, press the coils together firmly to tighten it up. The coils of the spring should not be too tight, as this will lead to bending and/or breaking of the component leads when they are inserted or removed. If a spring gets pushed over, light pressure will get it straightened back up.

The components, primarily resistors, and small wires can be stored in the plastic container at the top of the board. Encourage students to keep careful track of the components and return them to the container each day following the lab period.

When connecting a circuit to a D-cell, note the polarity (+ or -) which is printed on the board. In some cases the polarity is not important, but in some it will be imperative. Polarity is very important for most meters.

Connections are made on the Circuits Experiment Board by pushing a stripped wire or a lead to a component into a spring. For maximum effect, the stripped part of the wire should extend so that it passes completely across the spring, making contact with the spring at four points. This produces the most secure electrical and mechanical connection.
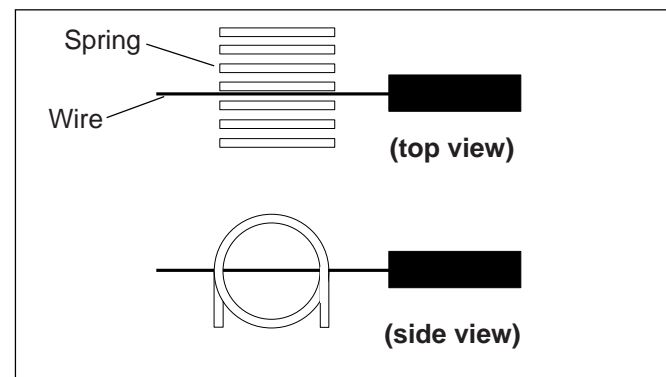
Figure 1 Diagram of wires and springs

Experiment 1: Circuits Experiment Board

EQUIPMENT NEEDED:

-Circuits Experiment   -Board
-D-cell Battery   -Wire Leads
-Graph   -Paper

Purpose

The purpose of this lab is to become familiar with the Circuits Experiment Board, to learn how to construct a complete electrical circuit, and to learn how to represent electrical circuits with circuit diagrams.

Background

① Many of the key elements of electrical circuits have been reduced to symbol form. Each symbol represents an element of the device's operation, and may have some historical significance. In this lab and the ones which follow, we will use symbols frequently, and it is necessary you learn several of those symbols.
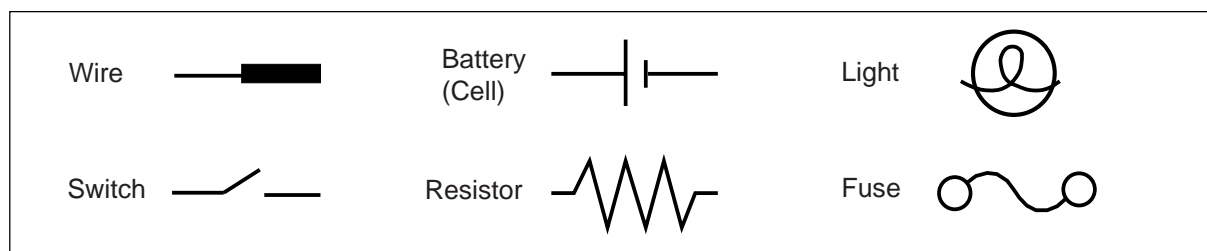
② The Circuits Experiment Board has been designed to conduct a wide variety of experiments easily and quickly. A labeled pictorial diagram of the Experiment Board appears on page 6. Refer to that page whenever you fail to understand a direction which mentions a device on the board itself.

③ **Notes on the Circuits Experiment Board:**

a) The springs are soldered to the board to serve as convenient places for connecting wires, resistors and other components. Some of the springs are connected electrically to devices like the potentiometer and the D-cells.

b) If a spring is too loose, press the coils together firmly to enable it to hold a wire more tightly. If a spring gets pushed over, light pressure will get it straightened back up. If you find a spring which doesn't work well for you, please notify your instructor.

c) The components, primarily resistors, are contained in a plastic case at the top of the board. Keep careful track of the components and return them to the storage case following each lab period. This way you will get components with consistent values from lab to lab.

d) When you connect a circuit to a D-cell (each "battery" is just a cell, with two or more cells comprising a battery) note the polarity (+ or -) which is printed on the board. Although in some cases the polarity may not be important, in others it may very important.

e) Due to normal differences between light bulbs, the brightness of "identical" bulbs may vary substantially.

Procedure

① Use two pieces of wire to make connections between the springs on one of the light bulbs to the springs on the D-cell in such a way that the light will glow. Discuss with your lab partner before you begin actually wiring your circuit which connections you intend to make, and why you think you will be successful in activating the light. If you are not successful, try in order: changing the wiring, using another light, using another cell, asking the instructor for assistance.

    a) Sketch the connections that the wires make when you are successful, using the symbols from the first page of this lab.

    b) Re-sketch the total circuit that you have constructed, making the wires run horizontally and vertically on the page. This is more standard in terms of drawing electrical circuits.

② Reverse the two wires at the light. Does this have any effect on the operation? Reverse the two wires at the cell. Does this have any effect on the operation?

③ In the following steps, use a vacant spring connection such as one of the three around the transistor socket as shown on the right as a "switch." Connect one lead from the battery to this spring and then take a third wire from the spring to the light. You can now switch the power "on" and "off" by connecting or not connecting the third wire.
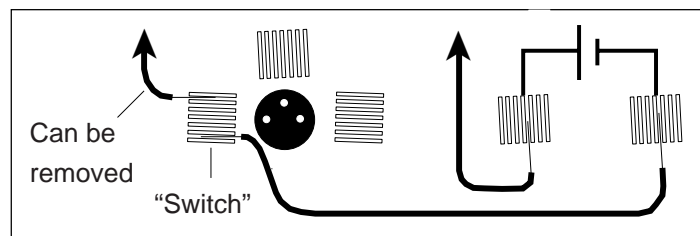
Figure 1.1

④ Use additional wires as needed to connect a second light into the circuit in such a way that it is also lighted. (Use a "switch" to turn the power on and off once the complete wiring has been achieved.) Discuss your plans with your lab partner before you begin. Once you have achieved success, sketch the connections that you made in the form of a circuit diagram. Annotate your circuit diagram by making appropriate notes to the side indicating what happened with that particular circuit. If you experience lack of success, keep trying.

➤ **NOTE:** Is your original light the same brightness, or was it brighter or dimmer that it was during step 1? Can you explain any differences in the brightness, or the fact that it is the same? If not, don't be too surprised, as this will be the subject of future study.

⑤ If you can devise another way of connecting two lights into the same circuit, try it out. Sketch the circuit diagram when finished and note the relative brightness. Compare your brightness with what you achieved with a single light by itself.

⑥ Disconnect the wires. Return the components and wires to the plastic case on the Circuits Experiment Board. Return the equipment to the location indicated by your instructor.
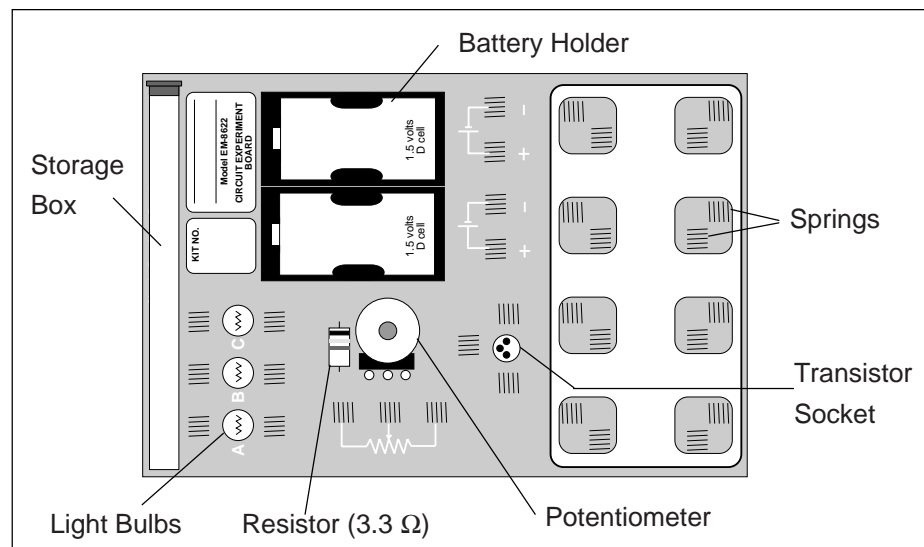
Figure 1.2

Experiment 2: Lights in Circuits

EQUIPMENT NEEDED:

-Circuits Experiment Board   -Two D-cell Batteries
-Wire Leads   -Graph Paper.

Purpose

The purpose of this lab is to determine how light bulbs behave in different circuit arrangements. Different ways of connecting two batteries will also be investigated.

Procedure

PART A

➤ **NOTE:** Due to variations from bulb to bulb, the brightness of one bulb may be substantially different from the brightness of another bulb in "identical" situations.

① Use two pieces of wire to connect a single light bulb to one of the D-cells in such a way that the light will glow. Include a "switch" to turn the light on and off, preventing it from being on continuously. (You should have completed this step in Experiment 1. If that is the case, review what you did then. If not, continue with this step.)

② Use additional wires as needed to connect a second light into the circuit in such a way that it is also lighted. Discuss your plans with your lab partner before you begin. Once you have achieved success, sketch the connections that you made in the form of a circuit diagram using standard symbols. Annotate your circuit diagram by making appropriate notes to the side indicating what happened with that particular circuit.

➤ **NOTE:** Is your original light the same brightness, or was it brighter or dimmer than it was during step 1? Can you explain any differences in the brightness, or why it is the same?

③ If one of the light bulbs is unscrewed, does the other bulb go out or does it stay on? Why or why not?

④ Design a circuit that will allow you to light all three lights, with each one being equally bright. Draw the circuit diagram once you have been successful. If you could characterize the circuit as being a series or parallel circuit, which would it be? What happens if you unscrew one of the bulbs? Explain.

⑤ Design another circuit which will also light all three bulbs, but with the bulbs all being equally bright, even though they may be brighter or dimmer than in step 4. Try it. When you are successful, draw the circuit diagram. What happens if you unscrew one of the bulbs? Explain.

⑥ Devise a circuit which will light two bulbs at the same intensity, but the third at a different intensity. Try it. When successful, draw the circuit diagram. What happens if you unscrew one of the bulbs? Explain.

➤ **NOTE:** Are there any generalizations that you can state about different connections to a set of lights?

PART B

⑦ Connect a single D-cell to a single light as in step 1, using a spring clip "switch" to allow you to easily turn the current on and off. Note the brightness of the light.

⑧ Now connect the second D-cell into the circuit as shown in Figure 2.1a. What is the effect on the brightness of the light?
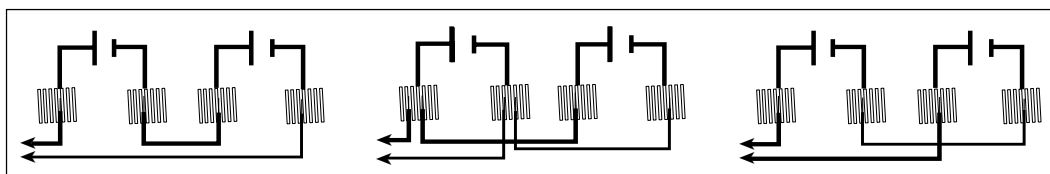
Figure 2.1a   **Figure 2.1b**   **Figure 2.1c**

⑨ Connect the second D-cell as in Figure 2.1b. What is the effect on the brightness?

⑩ Finally, connect the second D-cell as in figure 2.1c. What is the effect on the brightness?

➤ **NOTE:** Determine the nature of the connections between the D-cells you made in steps 8-10. Which of these was most useful in making the light brighter? Which was least useful? Can you determine a reason why each behaved as it did?

PART C

⑪ Connect the circuit shown in Figure 2.2. What is the effect of rotating the knob on the device that is identified as a "Potentiometer?"

Discussion

① Answer the questions which appear during the experiment procedure. Pay particular attention to the **"NOTED:"** questions.

② What are the apparent rules for the operation of lights in series? In parallel?

③ What are the apparent rules for the operation of batteries in series? In parallel?

④ What is one function of a potentiometer in a circuit?
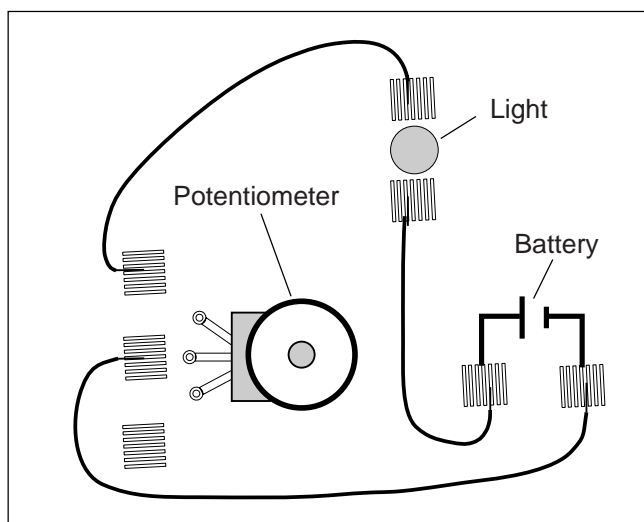
Figure 2.2 (Not to scale)

Experiment 3: Ohm's Law

EQUIPMENT NEEDED:

-Circuits Experiment Board
-Multimeter
-Graph Paper.

-D-cell Battery
-Wire Leads

Purpose

The purpose of this lab will be to investigate the three variables involved in a mathematical relationship known as Ohm's Law.

Procedure

① Choose one of the resistors that you have been given. Using the chart on the back, decode the resistance value and record that value in the first column of Table 3.1.
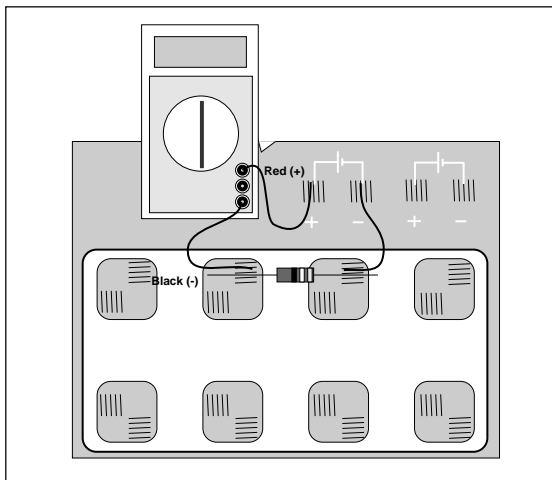
Figure 3.1a
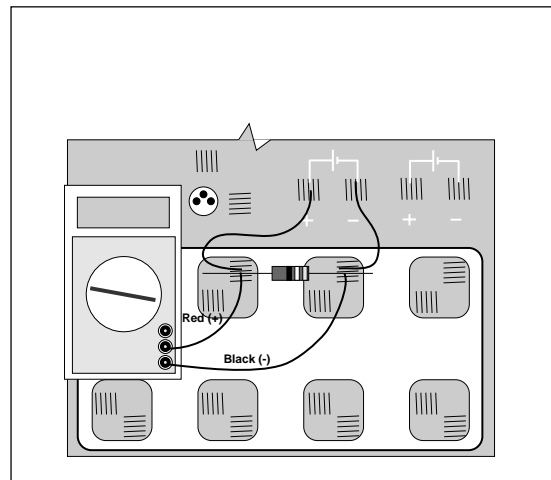
Figure 3.1b

② **MEASURING CURRENT:** Construct the circuit shown in Figure 3.1a by pressing the leads of the resistor into two of the springs in the Experimental Section on the Circuits Experiment Board.

③ Set the Multimeter to the 200 mA range, noting any special connections needed for measuring current. Connect the circuit and read the current that is flowing through the resistor. Record this value in the second column of Table 3.1.

④ Remove the resistor and choose another. Record its resistance value in Table 3.1 then measure and record the current as in steps 2 and 3. Continue this process until you have completed all of the resistors you have been given. As you have more than one resistor with the same value, keep them in order as you will use them again in the next steps.

⑤ **MEASURING VOLTAGE:** Disconnect the Multimeter and connect a wire from the positive lead (spring) of the battery directly to the first resistor you used as shown in Figure 3.1b. Change the Multimeter to the 2 VDC scale and connect the leads as shown also in Figure 3.1b. Measure the voltage across the resistor and record it in Table 3.1.

⑥ Remove the resistor and choose the next one you used. Record its voltage in Table 3.1 as in step 5. Continue this process until you have completed all of the resistors.

Data Processing

① Construct a graph of Current (vertical axis) vs Resistance.

② For each of your sets of data, calculate the ratio of Voltage/Resistance. Compare the values you calculate with the measured values of the current.

Resistance, Ω	Current, amp	Voltage, volt	Voltage/Resistance

Table 3.1

Discussion

① From your graph, what is the mathematical relationship between Current and Resistance?

② Ohm's Law states that current is given by the ratio of voltage/resistance. Does your data concur with this?

③ What were possible sources of experimental error in this lab? Would you expect each to make your results larger or to make them smaller?

Reference
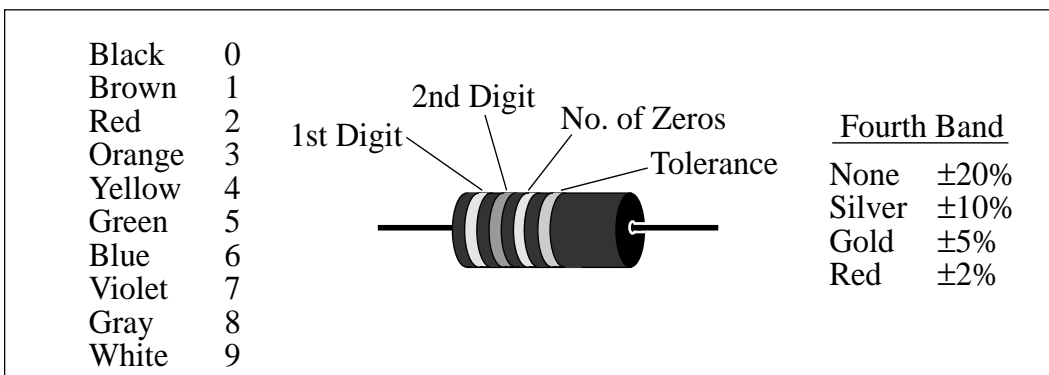
Figure 3.2

Experiment 4: Resistances in Circuits

EQUIPMENT NEEDED:

-Circuits Experiment Boar
- Multimeter
-Resistors.

Purpose

The purpose of this lab is to begin experimenting with the variables that contribute to the operation of an electrical circuit. This is the first of a three connected labs.

Procedure

① Choose the three resistors having the same value. Enter those sets of colors in Table 4.1 below. We will refer to one as #1, another as #2 and the third as #3.

② Determine the coded value of your resistors. Enter the value in the column labeled "Coded Resistance" in Table 4.1. Enter the Tolerance value as indicated by the color of the fourth band under "Tolerance."

③ Use the Multimeter to measure the resistance of each of your three resistors. Enter these values in Table 4.1.

④ Determine the percentage experimental error of each resistance value and enter it in the appropriate column.

Experimental Error = [(|Measured - Coded|) / Coded] x 100%.

	Colors 1st 2nd 3rd 4th	Coded Resistance	Measured Resistance	% Error	Tolerance
#1					
#2					
#3					

Table 4.1

⑤ Now connect the three resistors into the SERIES CIRCUIT, figure 4.1, using the spring clips on the Circuits Experiment Board to hold the leads of the resistors together without bending them. Measure the resistances of the combinations as indicated on the diagram by connecting the leads of the Multimeter between the points at the ends of the arrows.

Series

$R_{12}=$ _____

$R_{23}=$ _____

$R_{123}=$ _____
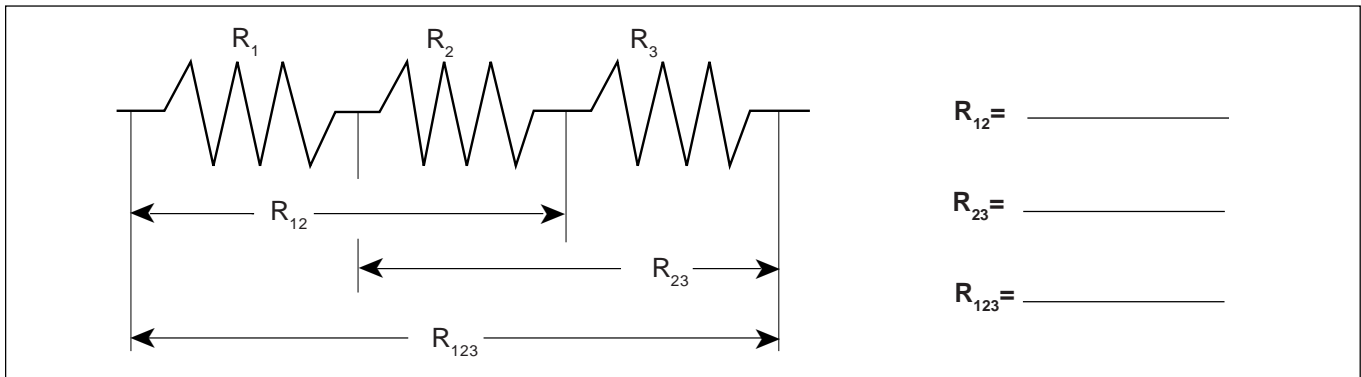
Figure 4.1

⑥ Construct a PARALLEL CIRCUIT, first using combinations of two of the resistors, and then using all three. Measure and record your values for these circuits.

Parallel

➤ **NOTE:** Include also R_{13}

⑦ Connect the COMBINATION CIRCUIT below and measure the various combinations of resistance. Do these follow the rules as you discovered them before?

$R_{12}=$ _____

$R_{23}=$ _____

$R_{123}=$ _____

Combination

Figure 4.2

$R_1 =$ _____

$R_{23} =$ _____

$R_{123}=$ _____
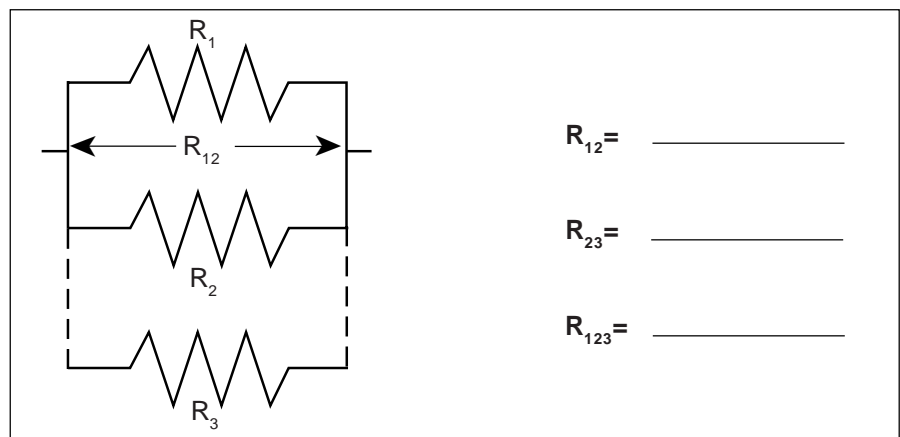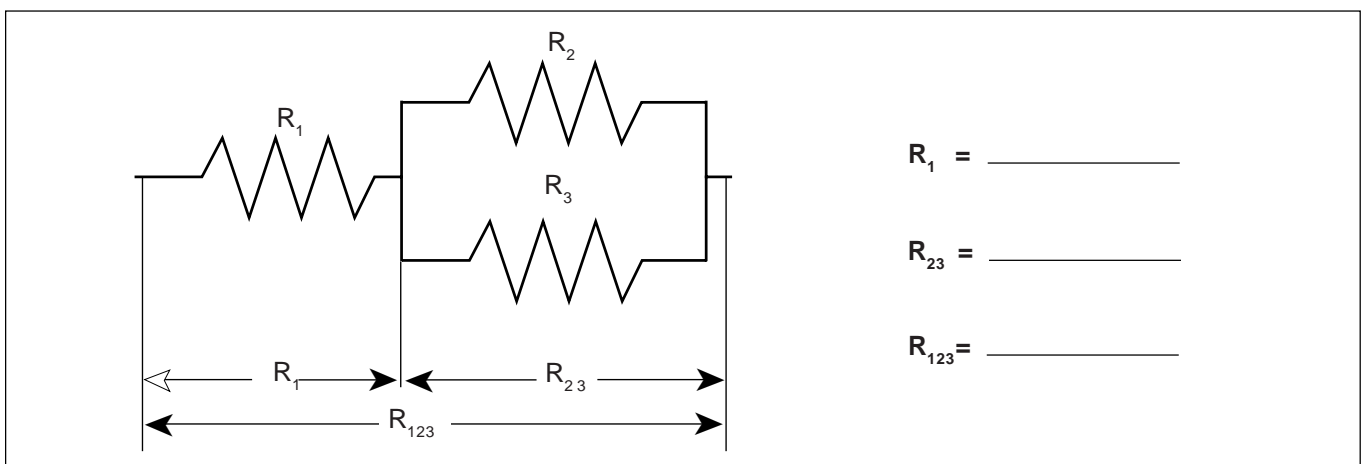
Figure 4.3

⑧ Choose three resistors having different values. Repeat steps 1 through 7 as above, recording your data in the spaces on the next page. Note we have called these resistors A, B and C.

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	Colors				Coded Resistance	Measured Resistance	% Error	Tolerance
	1st	2nd	3rd	4th				
A								
B								
C								

Table 4.2

Series

$R_{AB} =$ _____

$R_{BC} =$ _____
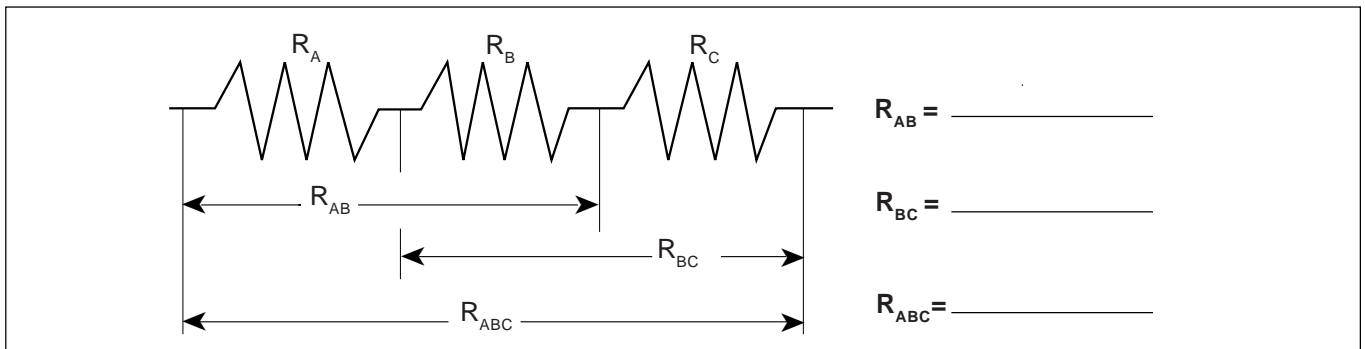
$R_{ABC} =$ _____

Figure 4.4

Parallel

$R_{AB} =$ _____

$R_{BC} =$ _____
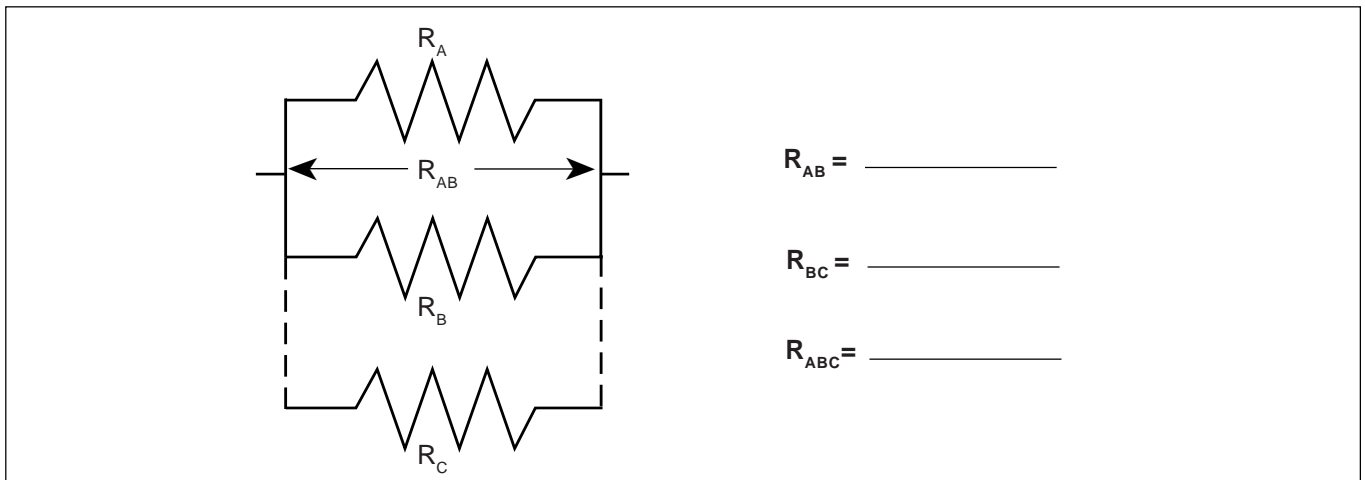
$R_{ABC} =$ _____

Figure 4.5

➤ **NOTE:** Include also R_{AC}

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Combination
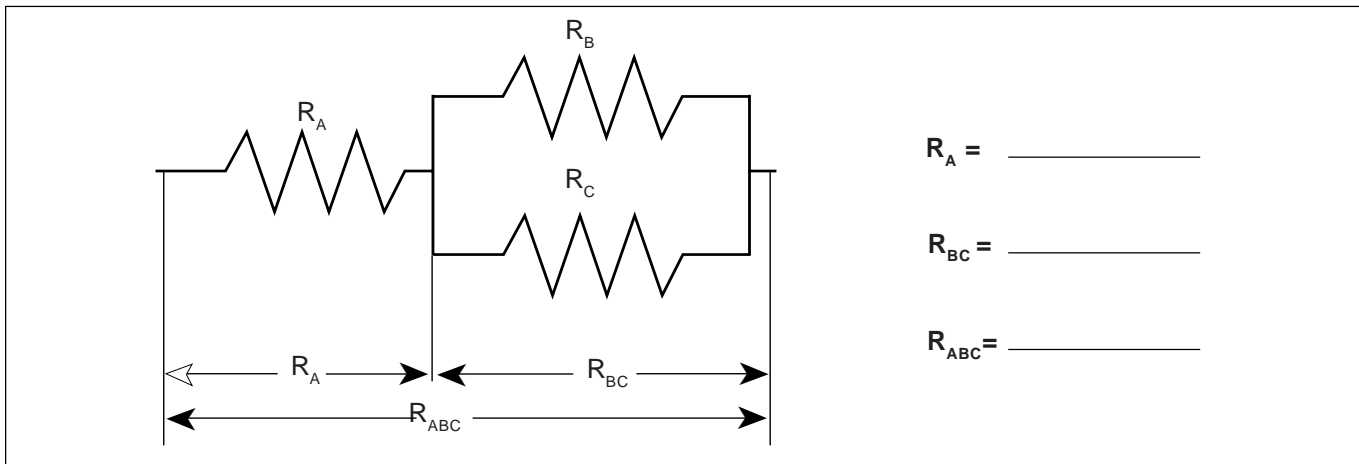
Figure 4.6

Discussion

① How does the % error compare to the coded tolerance for your resistors?

② What is the apparent rule for combining equal resistances in series circuits? In parallel circuits? Cite evidence from your data to support your conclusions.

③ What is the apparent rule for combining unequal resistances in series circuits? In parallel circuits? Cite evidence from your data to support your conclusions.

④ What is the apparent rule for the total resistance when resistors are added up in series? In parallel? Cite evidence from your data to support your conclusions.

Extension

Using the same resistance values as you used before plus any wires needed to help build the circuit, design and test the resistance values for another combination of three resistors. As instructed, build circuits with four and five resistors, testing the basic concepts you discovered in this lab.

Reference

Figure 4.7

Experiment 5: Voltages in Circuits

EQUIPMENT NEEDED:

-Circuits Experiment Board   -Multimeter
-D-cell Battery   -Resistors
-Wire Leads

Purpose

The purpose of this lab will be to continue experimenting with the variables that contribute to the operation of an electrical circuit. You should have completed Experiment 4 before working on this lab.

Procedure

① Connect the three equal resistors that you used in Experiment 4 into the series circuit shown below, using the springs to hold the leads of the resistors together without bending them. Connect two wires to the D-cell, carefully noting which wire is connected to the negative and which is connected to the positive.

② Now use the voltage function on the Multimeter to measure the voltages across the individual resistors and then across the combinations of resistors. Be careful to observe the polarity of the leads (red is +, black is -). Record your readings below.

Series
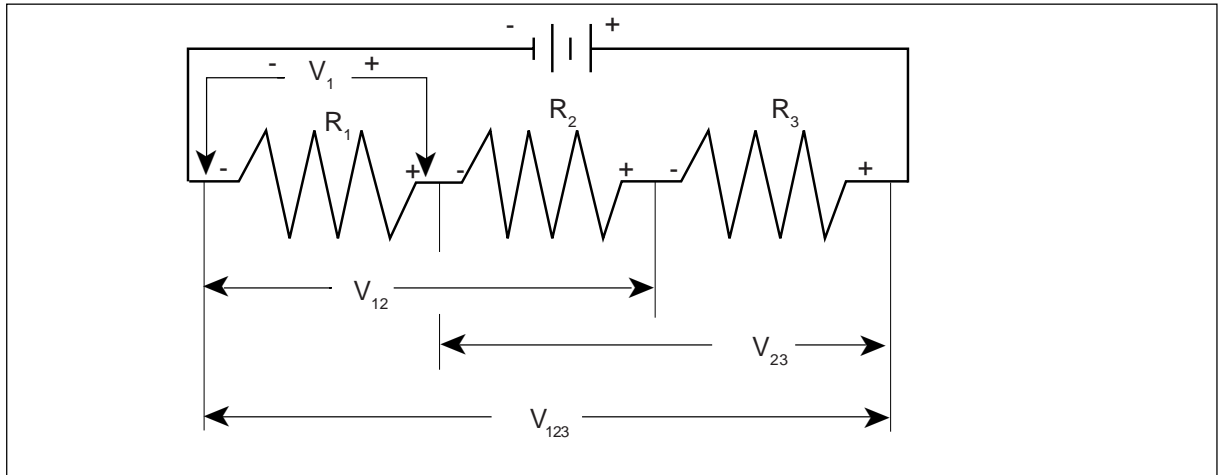
Figure 5.1

R_1 = _____ V_1 =   _____

R_2 = _____ V_2 =   _____

R_3 = _____ V_3 =   _____

R_{12} = _____ V_{12} =   _____

R_{23} = _____ V_{23} =   _____

R_{123}= _____ V_{123}=   _____

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③ Now connect the parallel circuit below, *using all three resistors*. Measure the voltage across each of the resistors and the combination, taking care with the polarity as before.

➤**NOTE:** Keep all three resistors connected throughout the time you are making your measurements. Write down your values as indicated below.

Parallel

R_1 = _____ V_1 = _____

R_2 = _____ V_2 = _____

R_3 = _____ V_3 = _____

R_{123}= _____ V_{123}= _____
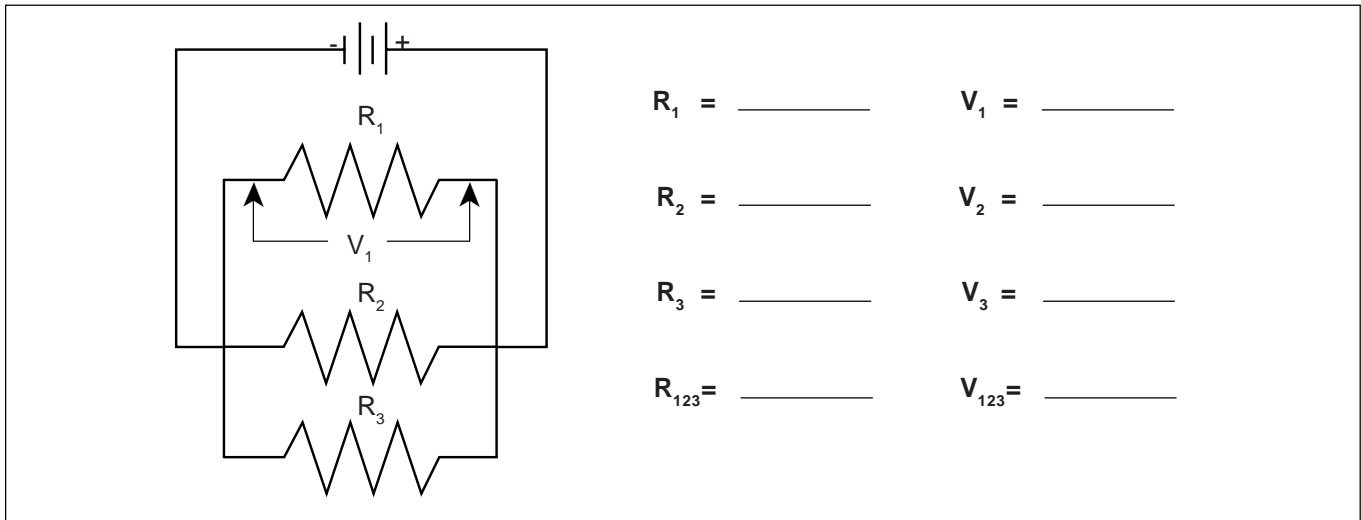
Figure 5.2

④ Now connect the circuit below and measure the voltages. You can use the resistance readings you took in Experiment 4 for this step.

Combination

R_1 = _____ V_1 = _____

R_{23} = _____ V_{23} = _____

R_{123} = _____ V_{123} = _____
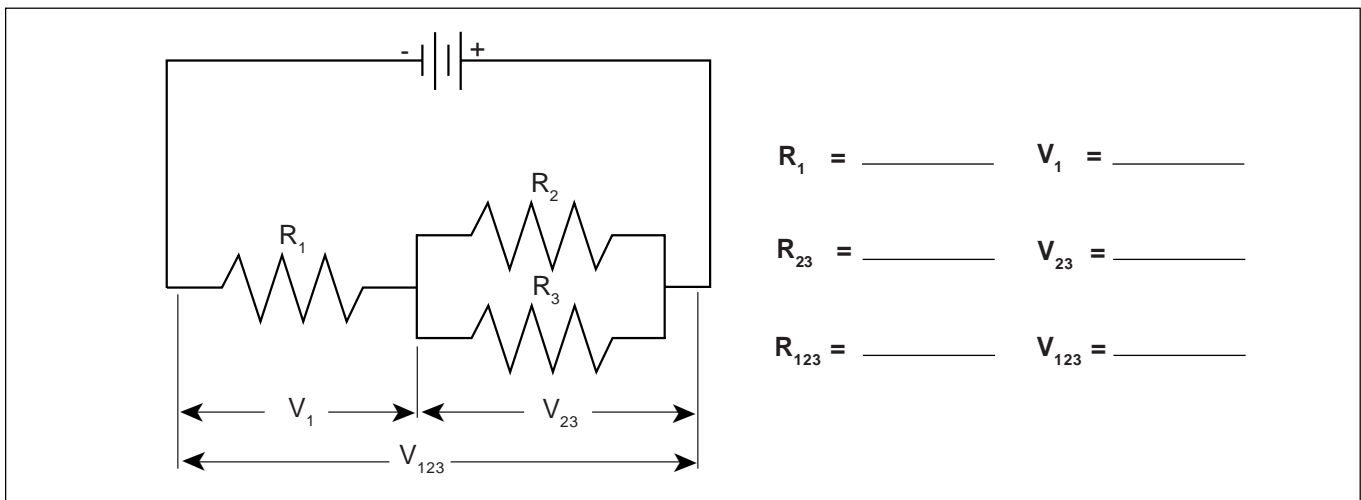
Figure 5.3

⑤ Use the three unequal resistors that you used in Experiment 4 to construct the circuits shown below. Make the same voltage measurements that you were asked to make before in steps 1 to 4. Use the same resistors for A, B and C that you used in Experiment 4.

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Series
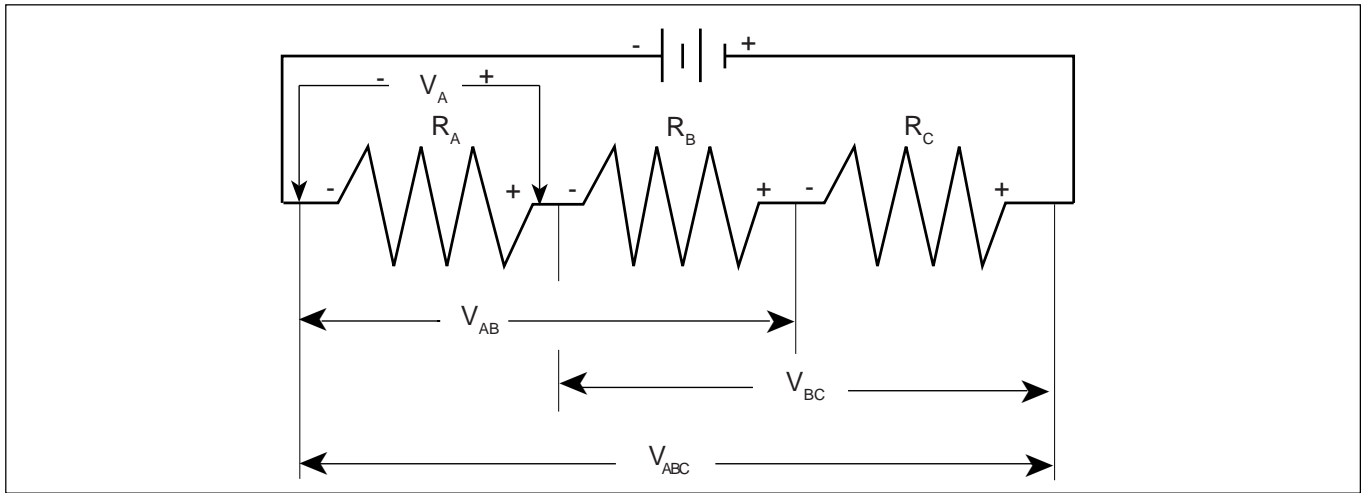
Figure 5.4

R_A = _____ V_A = _____

R_B = _____ V_B = _____

R_C = _____ V_C = _____

R_{AB} = _____ V_{AB} = _____

R_{BC} = _____ V_{BC} = _____

R_{ABC} = _____ V_{ABC} = _____

Parallel
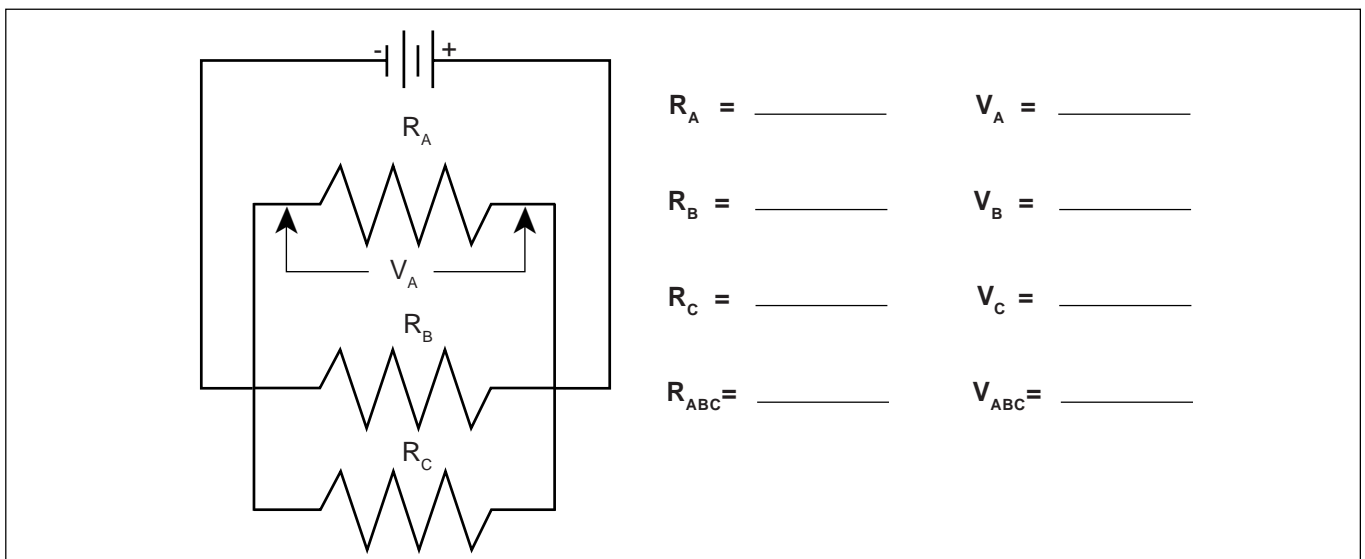
R_A = _____ V_A = _____

R_B = _____ V_B = _____

R_C = _____ V_C = _____

R_{ABC} = _____ V_{ABC} = _____

Figure 5.5

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Combination

R_A = _____ V_A = _____

R_{BC} = _____ V_{BC} = _____

R_{ABC} = _____ V_{ABC} = _____
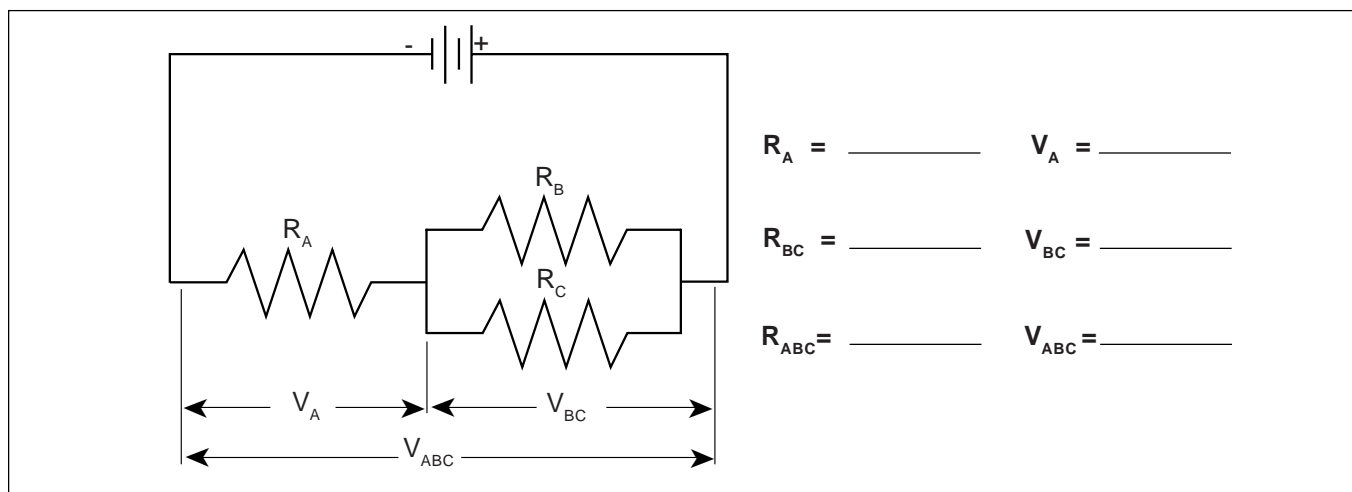
Figure 5.6

Discussion

On the basis of the data you recorded on the table with Figure 5.1, what is the pattern for how voltage gets distributed in a series circuit with equal resistances? According to the data you recorded with Figure 5.4, what is the pattern for how voltage gets distributed in a series circuit with unequal resistances? Is there any relationship between the size of the resistance and the size of the resulting voltage?

Utilizing the data from Figure 5.2, what is the pattern for how voltage distributes itself in a parallel circuit for equal resistances? Based on the data from Figure 5.5, what is the pattern for how voltage distributes itself in a parallel circuit for unequal resistances? Is there any relationship between the size of the resistance and the size of the resulting voltage?

Do the voltages in your combination circuits (see Figures 5.3 and 5.6) follow the same rules as they did in your circuits which were purely series or parallel? If not, state the rules you see in operation.

Experiment 6: Currents in Circuits

EQUIPMENT NEEDED:

-Circuits Experiment Board   -Digital Multimeter
-Resistors   -D-cell Battery
-Wire Leads.

Purpose

The purpose of this lab will be to continue experimenting with the variables that contribute to the operation of electrical circuits.

Procedure

① Connect the same three resistors that you used in Experiments 3 and 4 into the series circuit shown below, using the springs to hold the leads of the resistors together without bending them. Connect two wires to the D-cell, and carefully note which lead is negative and which is positive.

Series

② Now change the leads in your DMM so that they can be used to measure current. You should be using the scale which goes to a maximum of 200 mA. Be careful to observe the polarity of the leads (red is +, black is -). In order to measure current, the circuit must be interrupted, and the current allowed to flow through the meter. Disconnect the lead wire from the positive terminal of the battery and connect it to the red (+) lead of the meter. Connect the black (-) lead to R_1, where the wire originally was connected. Record your reading in the table as I_0. See Figure 6.2.

Figure 6.1

③ Now move the DMM to the positions indicated in Figure 6.3, each time interrupting the circuit, and carefully measuring the current in each one. Complete the table on the top of the back page.
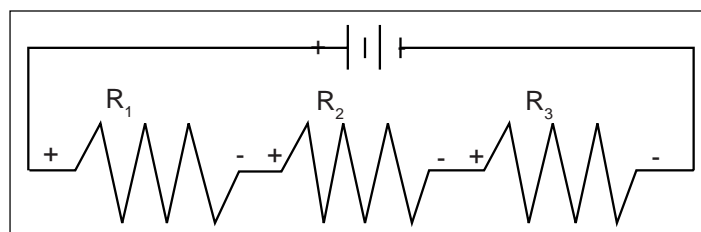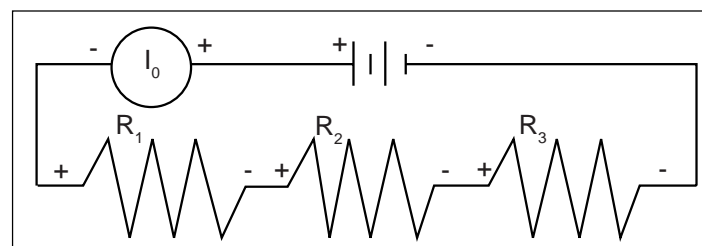
Figure 6.2

➤ **NOTE:** You will be carrying values from Experiments 3 and 4 into the table on the back.
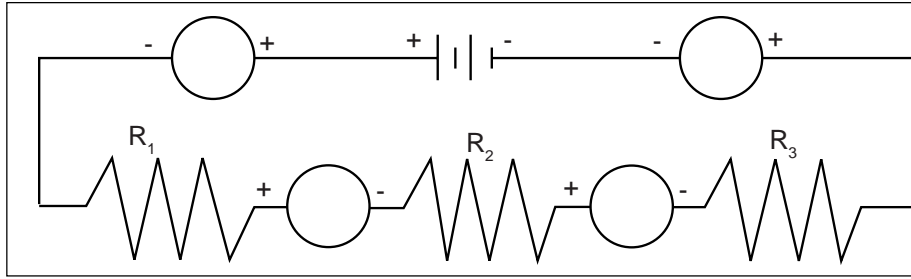
Figure 6.3

R_1 =_____ I_0 =_____ V_1 =_____

R_2 =_____ I_1 =_____ V_2 =_____

R_3 =_____ I_2 =_____ V_3 =_____

R_{12} =_____ I_3 =_____ V_{12} =_____

R_{23} =_____ V_{23} =_____

R_{123}=_____ V_{123}=_____

④ Connect the parallel circuit below, using all three resistors. Review the instructions for connecting the DMM as an ammeter in step 2. Connect it first between the positive terminal of the battery and the parallel circuit junction to measure I_0. Then interrupt the various branches of the parallel circuit and measure the individual branch currents. Record your measurements in the table below.

Parallel

R_1 =_____ I_0 =_____ V_1 =_____

R_2 =_____ I_1 =_____ V_2 =_____

R_3 =_____ I_2 =_____ V_3 =_____

R_{123} =_____ I_3 =_____ V_{123} =_____

                    I_4 =_____
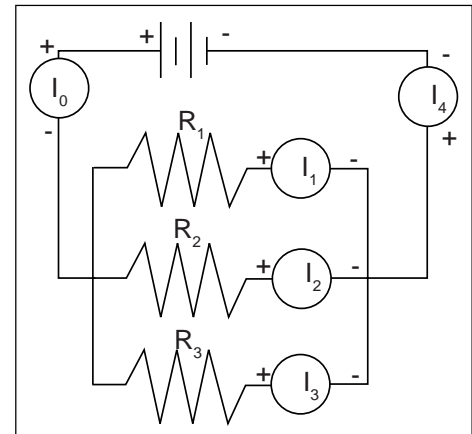
Figure 6.4

Discussion

On the basis of your first set of data, what is the pattern for how current behaves in a series circuit? At this point you should be able to summarize the behavior of all three quantities - resistance, voltage and current - in series circuits.

On the basis of your second set of data, are there any patterns to the way that currents behave in a parallel circuit? At this time you should be able to write the general characteristics of currents, voltages and resistances in parallel circuits.

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Experiment 7: Kirchhoff's Rules

EQUIPMENT NEEDED:

-Circuits Experiment Board   -Two D-cell Batteries
-Wire Leads   -Digital Multimeter (DMM)
-Resistors.

Purpose

The purpose of this lab will be to experimentally demonstrate Kirchhoff's Rules for electrical circuits.

Procedure

① Connect the circuit shown in Figure 7.1a using any of the resistors you have except the 10 Ω one. Use Figure 7.1b as a reference along with 7.1a as you record your data. Record the resistance values in the table below. With no current flowing (the battery disconnected), measure the total resistance of the circuit between points **A** and **B**.
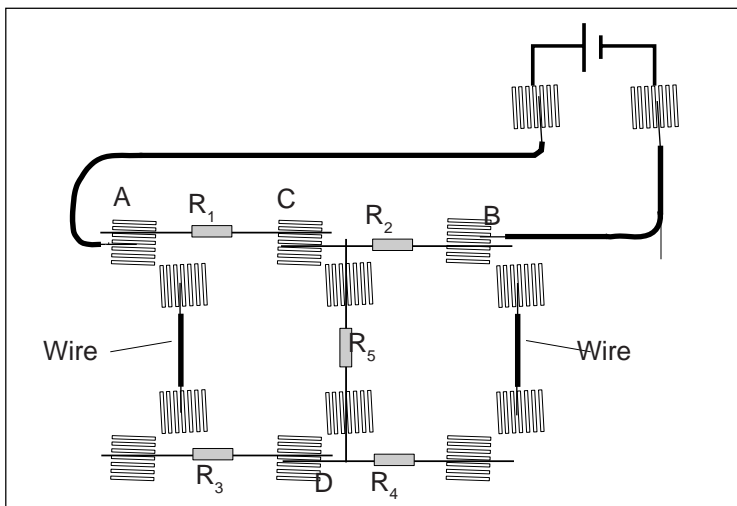
Figure 7.1a
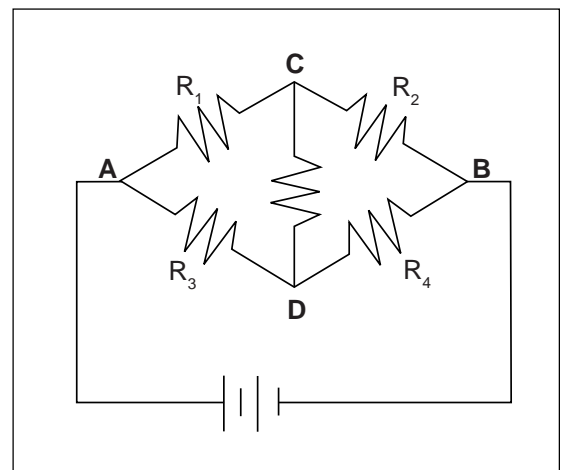
Figure 7.1b

② With the circuit connected to the battery and the current
flowing, measure the voltage across each of the resistors and record the values in the table below.
On the circuit diagram in Figure 7.1b, indicate which side of each of the resistors is positive
relative to the other end by placing a "+" at that end.

③ Now measure the current through each of the resistors. Interrupt the circuit and place the DMM
in series to obtain your reading. Make sure you record each of the individual currents, as well as
the current flow into or out of the main part of the circuit, **I$_T$**.

Resistance, Ω	Voltage, volts	Current, mA
R_1	V_1	I_1
R_2	V_2	I_2
R_3	V_3	I_3
R_4	V_4	I_4
R_5	V_5	I_5
R_T	V_T	I_T

Table 7.1

Analysis

① Determine the net current flow into or out of each of the four "nodes" in the circuit.

② Determine the net voltage drop around at least three (3) of the six or so closed loops. Remember, if the potential goes up, treat the voltage drop as positive (+), while if the potential goes down, treat it as negative (-).

Discussion

Use your experimental results to analyze the circuit you built in terms of Kirchhoff's Rules. Be specific and *state the evidence* for your conclusions.

Extension

Build the circuit below and apply the same procedure you used previously. Analyze it in terms of Kirchhoff's Rules. If possible, try to analyze the circuit ahead of time and compare your measured values with the theoretically computed values.
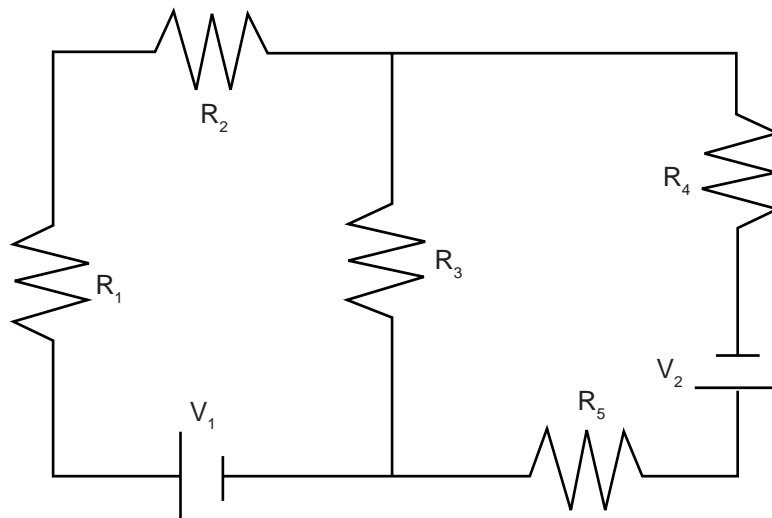
Figure 7.2

Experiment 8: Capacitors in Circuits

EQUIPMENT NEEDED:

– Vacuum Tube Voltmeter (VTVM) or Electrometer (ES-9054B) or Digital Multimeter (DMM) that has an input impedance of 10 MΩ or greater.

– Circuits Experiment Board
– Capacitors, Resistors
– Wire Leads
– D-cell Battery
– Stopwatch or timer with 0.1 sec resolution.

Purpose

The purpose of this lab will be to determine how capacitors behave in R-C circuits. The manner in which capacitors combine will also be studied.

Procedure

① Connect the circuit shown in Figure 8.1, using a 100-K Ω resistor and a 100-µF capacitor. Use one of the spring clips from the transistor socket as a "switch" as shown. Connect the VTVM so the black "ground" lead is on the side of the capacitor that connects to the negative terminal of the battery and set it so that it reads to a maximum of 1.5 V DC.

② Start with no voltage on the capacitor and the wire from the "switch" to the circuit disconnected. If there is a remaining voltage on the capacitor, use a piece of wire to "short" the two leads together, draining any remaining charge. (Touch the ends of the wire to points **B** and **C** as shown in Figure 1 to discharge the capacitor.)

③ Now close the "switch" by touching the wire to the spring clip. Observe the voltage readings on the VTVM, the voltage across the capacitor. How would you describe the manner in which the voltage changes?

Figure 8.1

④ If you now open the "switch" by removing the wire from the spring clip, the capacitor should remain at its present voltage with a very slow drop over time. This indicates that the charge you placed on the capacitor has no way to move back to neutralize the excess charges on the two plates.

⑤ Connect a wire between points **A** and **C** in the circuit, allowing the charge to drain back through the resistor. Observe the voltage readings on the VTVM as the charge flows back. How would you describe the manner in which the voltage falls? (It would be reasonable to sketch a graph showing the manner in which the voltage rose over time as well as the manner in which it fell over time.)

⑥ Repeat steps 3-5 until you have a good feeling for the process of charging and discharging of a capacitor through a resistance.

⑦ Now repeat steps 3-5, this time recording the time taken to move from 0.0 volts to 0.95 volts while charging, t_C, and the time taken to move from 1.5 volts to 0.55 volts while discharging, t_D. Record your times along with the resistance and capacitance values in Table 8.1 at the top of the back page.
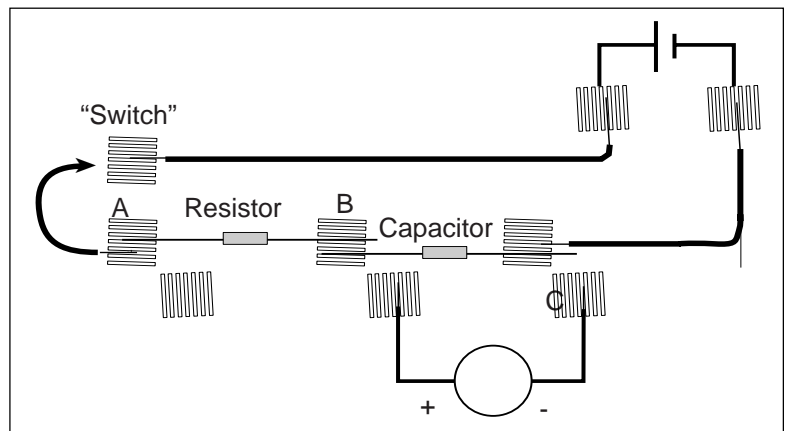
Trial	Resistance	Capacitance	t_C	t_D
1				
2				
3				
4				
5				
6				
7				
8				

Table 8.1

⑧ Replace the 100-µF capacitor with a 330-µF capacitor. Repeat step 7, recording the charging and discharging times in Table 8.1. If a third value is available, include it in the data table, too.

⑨ Return to the original 100-µF capacitor, but put a 220-K Ω resistor in the circuit. Repeat step 7, recording your data in Table 8.1. If a third resistor is provided, use it in the circuit, recording the data.

➤ **NOTE:**

① What is the effect on charging and discharging times if the capacitance is increased? What mathematical relationship exists between your times and the capacitance?

② What is the effect on charging and discharging times if the resistance of the circuit is increased? What mathematical relationship exists between your times and the resistance?

---

⑩ Return to the original 100-K Ω resistor, but use the 100-µF capacitor in series with the 330-µF capacitor. Repeat step 7, recording your results in Table 8.2.

⑪ Now repeat step 7, but with the 100-µF and the 330-µF capacitors in parallel.

$R =$ _____ $C_1 =$ _____ $C_2 =$ _____

Type of Circuit	t_C	t_D
Series		
Parallel		

Table 8.2

➤ **NOTE:** What is the effect on the total capacitance if capacitors are combined in series? What if they are combined in parallel? (Refer to Table 8.2).

Experiment 9: Diodes

EQUIPMENT NEEDED:

-Circuits Experiment Board   -Digital Multimeter (DMM)
-Wire Leads   -Two D-cell Batteries
-1000-Ω Resistor   -1N4007 Diode
-330-Ω Resistor.

Purpose

The purpose of this lab will be to experimentally determine some of the operating characteristics of semiconductor diodes.

Procedure

① Connect the circuit shown in Figure 9.1a using the 1N4007 diode you've been supplied and the 1000-Ω resistor. Use Figure 9.1b as a reference along with Figure 9.1a as you record your data. Note the direction that the diode is oriented, with the dark band closer to point **B**.

② With the "switch" closed and the current flowing, adjust the potentiometer until there is a voltage of 0.05 volt between points **B** and **C** (V_{BC}). Measure the voltage across the diode (V_{AB}). Record your values in the left-hand side of Table 9.1under "Forward Bias".

③ Adjust the potentiometer to attain the following values for V_{BC}: 0.1, 0.2, 0.3,.....2.0 volts. Record the two voltages for each case.

Figure 9.1a

④ Remove the 1000-Ω resistor and replace it with a 330-Ω resistor. Repeat steps 3 & 4, going from a voltage of 0.3, 0.4,.....2.0 volts. Record the two voltages in each case.

⑤ Reverse the orientation of the diode. Set the diode voltage (V_{AB}) to the values 0.5, 1.0,....3.0 volts. Measure the resistor voltage (V_{BC}) in each case. Record these values in the columns labeled "Reverse Bias".
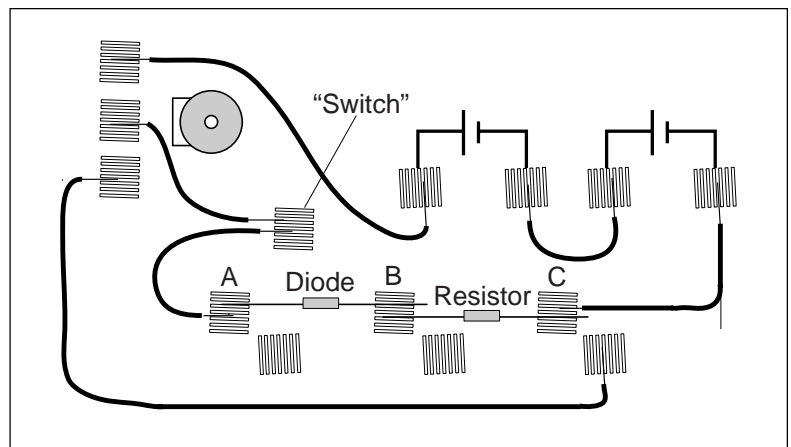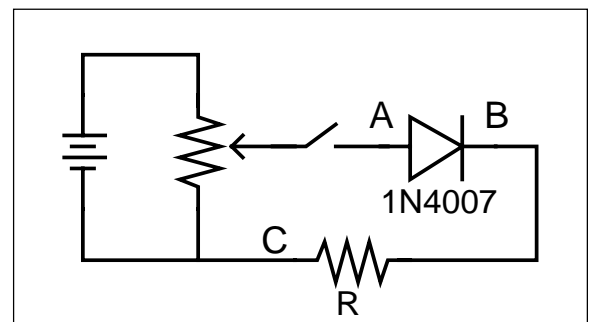
Analysis

① Determine the current flow (**I**) in each setting by dividing the voltage across the resistor (V_{BC}) by the resistance. Where you switched resistors, be sure to change the divisor.

Figure 9.1b

② Construct a graph of Current (vertical axis) vs the Voltage across the diode, with the graph extending into the 2nd quadrant to encompass the negative voltages on the diode.

Discussion

Discuss the shape of your graph and what it means for the operation of a semiconductor diode. Did the diode operate the same in steps 3 and 4 as it did in step 5? In steps 3 and 4 the diode was "Forward Biased", while it was "Reverse Biased" in step 5. Based on your data, what do you think these terms mean? What use might we have for diodes?

Sample Data Table

Diode Type _____

	Forward Bias				Reverse Bias		
R, Ω	V_{AB}, volts	V_{BC}, volts	I, mA	R, Ω	V_{AB}, volts	V_{BC}, volts	I, mA

Table 9.1

Extensions

① If your instructor has a zener diode, carry out the same investigations that you did above. What differences are there in basic diodes and zener diodes?

② Use an LED (light emitting diode) to carry out the same investigations. What differences are there between basic diodes and LED's?

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Experiment 10: Transistors

EQUIPMENT NEEDED:

-Circuits Experiment Board
-Wire Leads
-1000-Ω Resistor
-100-Ω Resistor.

-Two D-cell Batteries
-Digital Multimeter (DMM)
-2N3904 Transistor (NPN)

Purpose

The purpose of this lab will be to experimentally determine some of the operating characteristics of a transistor.

Procedure

① Connect the circuit shown in Figure 10.1a using the 2N3904 Transistor you've been supplied. Resistor R_1 = 1000 Ω and resistor R_2 = 100 Ω. Use Figure 10.1b as a reference along with Figure 10.1a as you record your data. Note the leads on the transistor as marked next to the socket in the drawing.
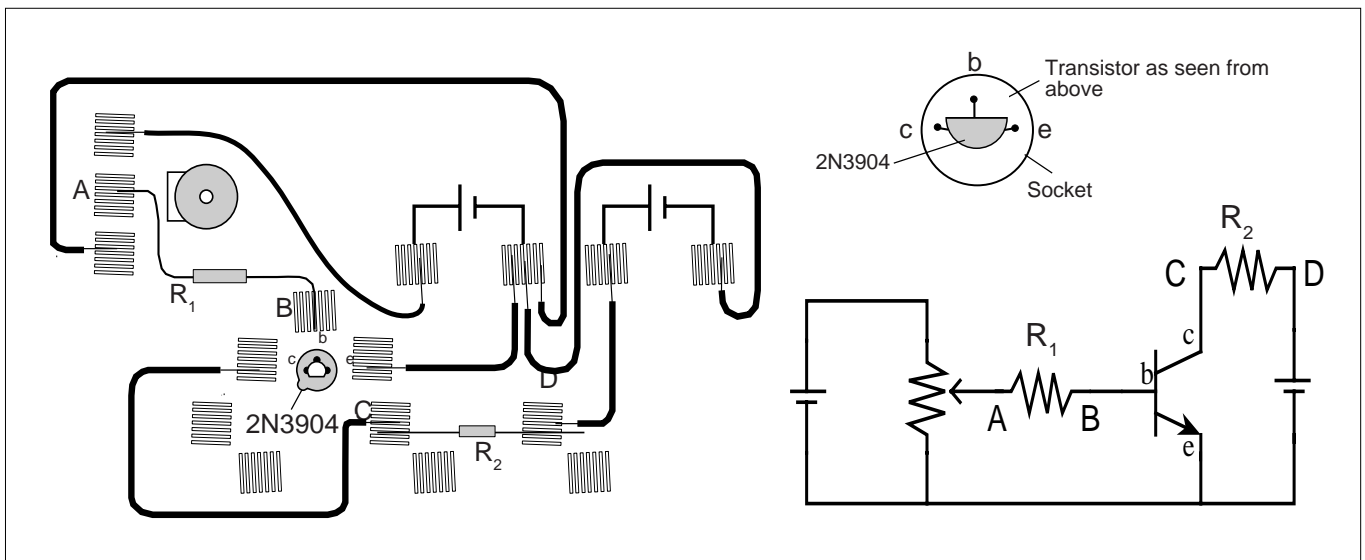
| Figure 10.1a | Figure 10.1b |

② Adjust the potentiometer carefully until the reading between points **A** and **B** is approximately 0.002 volt (2.0 mv). Now read the voltage between points **C** and **D**. Record these readings in your data table. Note that V_{AB} divided by R_1 gives the current flowing to the base of the transistor, while V_{CD} divided by R_2 gives the current flowing in the collector part of the circuit.

③ Adjust the potentiometer to give V_{AB} the following readings, each time reading and recording the corresponding V_{CD}: 0.006, 0.010, 0.015, 0.020, 0.025, 0.030, 0.035, 0.040, 0.045, 0.050, 0.055, 0.060, 0.080, 0.100, 0.150, 0.200, 0.250 volts. Also set V_{AB} to 0.000 volts.

Analysis

① For each of your sets of readings, calculate:

$$\mathbf{I_B = V_{AB} / R_1} \text{ and } \mathbf{I_C = V_{CD} / R_2}$$

Record all of your current readings in mA.

② Plot a graph of $\mathbf{I_C}$ (vertical axis) vs $\mathbf{I_B}$. If you find an area or areas where you need more points to fill out any curves or sudden changes, simply return to step 2 and make the appropriate measurements.

③ What is the general shape of the graph? Is there a straight-line region? Does it go through the origin? Why or why not? Relate the behavior of the transistor at the beginning of the graph to the behavior of the diode in Experiment 9.

④ What does the leveling off of the graph indicate? Electronics people refer to the transistor as being "saturated". How would you describe saturation based on your experiment?

⑤ Find the slope of the straight-line region of the graph. This ratio - $\mathbf{I_C} / \mathbf{I_B}$ is referred to as the current amplification of the transistor. It describes how many times greater changes in the collector current are than the changes in the base current. Report the current amplification of your transistor.

Discussion

Discuss the graph and the calculations you did in the Analysis section.

Sample Data Table

Transistor Type _____

R_1, Ω	V_{AB}, volts	I_B, mA	R_2, Ω	V_{CD}, volts	I_C, mA

Table 10.1

Extensions

① What effect would changing the resistance in the collector circuit ($\mathbf{R_2}$) make? Try changing the value to 330 Ω or 560 Ω. Does the graph have the same shape? Is the current amplification the same as before? How does the amplification depend on $\mathbf{R_2}$?

② Obtain a different transistor and repeat the measurements you made in steps 2 & 3. If it is a PNP transistor, you will need to reverse the wires coming from the D-cells as the emitter needs to be positive, not negative, and the collector will be negative.

Appendix: Tips and Troubleshooting

Correct Circuit, Doesn't Work

- Check to see if the circuit is indeed connected correctly and completely.

- Check to see if the battery is giving full voltage.

- Check to see if each wire is making contact with the spring. If magnet wire is used, the enamel coating on the outside will prevent electrical connection and needs to be removed. In some cases, students may try to make a complete circuit through the insulation.

Surprising Results

In some cases, there will be no difference in the measurements from one point in the circuit to another. This doesn't mean the measurement is trivial or unimportant, rather it is what we hope the student will learn from his/her lab work. Not all measurements have to be different.

Making a "switch"

In the several labs, students are asked to use a "vacant" spring connection such as one of the three around the transistor socket as shown on the right as a "switch." By connecting one lead from the battery there and then taking a third wire to the circuit, you can effectively switch the power "on" and "off" by simply connecting or not connecting the third wire. This duplicates the action in a real switch.
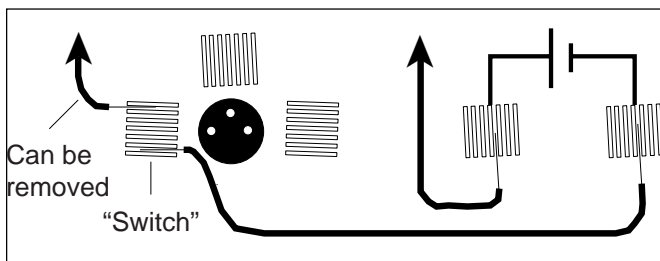
Figure 2

Lights and Relative Brightness

The lights for this experiment board, #14 bulbs, are designed for 2.5 volts and 0.3 amperes. A single D-cell will not light a bulb to maximum brightness, but two cells in series will give a very bright light.

The labs asking for relative brightness ask students to judge relative brightness only, not an absolute brightness. This part of the experiment would be aided by having the room mostly darkened. Additional bulbs can be purchased from PASCO, at Radio Shack, an electronics store, at auto supplies stores, or possibly a local discount store.

Batteries

The Circuits Experiment Board is designed to use one or two D-cells. The voltage delivered by a D-cell is 1.5 volts ±. In practice, alkaline cells give the longest life, but the less expensive zinc-carbon cells will give adequate results. A single set of batteries was used successfully by ten different classes to complete labs 1,3,4,5, 6 and 7 before being replaced.

Resistors

The resistors supplied are listed under Materials on page 1 of this manual. The values have been chosen for clear results and for helping to extend the life of the D-cells. If resistors are lost or broken, replacements can be purchased from PASCO, or at any electronics store, including Radio Shack. Other values can be substituted, but for Experiments 3 through 7, the values should be between 100 Ω and 1500 Ω for best results.

> ➤**NOTE:** Using the 330 Ω, 560 Ω and 1000 Ω resistors gives approximate ratios of 1:2:3 for working towards semi-quantitative understanding of d.c. circuits.

The diagram below shows the resistor color code. For example, a resistor having the colors Orange-Orange-Brown-Silver has the value 330 Ω ± 10%.

Figure 3

Wires

The Circuits Experiment Board can be used with a large variety of wire types and sizes. We recommend 20 or 22 gauge solid wire with colorful insulation. This will help students to follow their work more easily and minimize difficulties in making the transition from paper circuit to actual circuit on the Circuits Experiment Board.

Stripping Your Own Wire

The wire included with the Basic Electricity Lab is 22 gauge insulated, solid wire in 5" and 10" lengths. The lengths are stripped at each end.

If you choose to strip your own additional wires, a commercially available wire stripper can be used to remove the insulation from each end. The jaws of the wire stripper are placed on the wire 3/8" from the end. By squeezing the handles together, the jaws will close on the wire and cut only as deep as the insulation.

Figure 3a

Squeeze handles
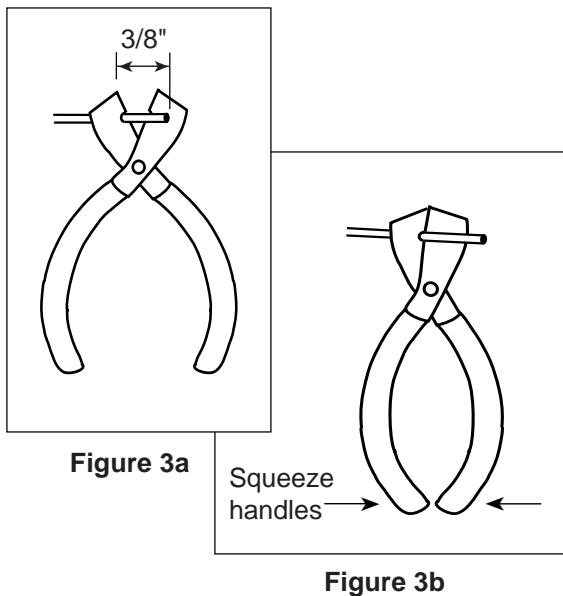
Figure 3b

Pulling the wire away from the stripper (Figure 3c) causes the cut end of the insulation to slip off of the wire, leaving 3/8" of exposed wire.

Pull wire
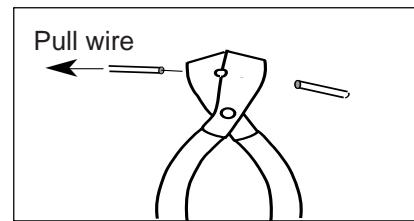
Figure 3c

If you do not have access to a wire stripper, the wire may also be stripped by carefully using a knife. Place the wire on a solid surface. Set the knife blade on the insulation about 3/8" from the end. With the blade at an angle so it cannot cut downward into the wire, use the knife to shave off the insulation.
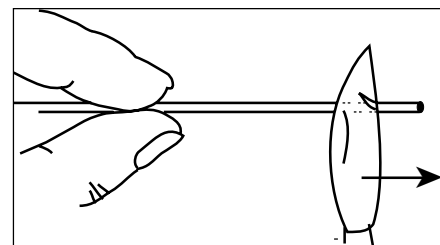
Figure 4

After one part of the insulation is removed, turn the wire and continue shaving off the rest of the insulation.

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Replacement Parts List

Item	PASCO Part #
P.C.B. ASSY, BASIC ELECT	004-04340
MANUAL EM-8622	012-04367
RES, 10 OHM, 1W, 5%	111-100
RES, 100 OHM, 1/2W, 5%	112-101
RES, 1K, 1/2W, 5%	112-102
RES, 100K, 1/2W, 5%	112-104
RES, 220K, 1/2W, 5%	112-224
RES, 330 OHM, 1/2W, 5%	112-331
RES, 560 OHM, 1/2W, 5%	112-561
CAP, ELECT-100mF, 16V AXIAL	222-039
CAP, ELECT 330MF, 16V AXIAL	222-040
DIODE-1N4007, 1000PIV, 1A	410-002
TRANSISTOR-2N3904 NPN	420-002

➤**NOTE:** Replacement parts can be purchased from PASCO or at most electronic stores including Radio Shack.

Notes

Teacher's Guide

Exp 1 - Circuits Experiment Board

①

② Reversing things at either end had no effect.

④⑤ There are two different ways of putting two lamps into the circuit: parallel and serial.

Parallel:
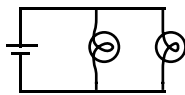
With this method, the lights will each be approximately the same brightness as in part 1.

Serial:
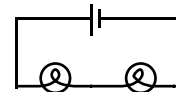
Using this circuit, the lights will be dimmer than in part 1.

Exp 2 - Lights in Circuits

➤**NOTE:** It is best to do these experiments with both batteries, rather than just one. Connect them in series, as shown in figure 2.1a. This will make the lights brighter and easier to see when some of the dimmer circuits are built.

Procedure

①

②③ There are two ways of making the circuit so that both lights are on with the same intensity.

Series
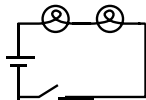
The lights will be dimmer than in part 1. The electric current must go through one bulb to reach the other, so disconnecting a bulb will cause both to go out. (This is how those maddening "if-one-goes-out-they-all-die-so-Merry-Christmas" lights are wired.)
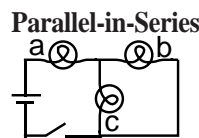
Parallel
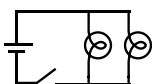
The lights will show the same intensity as in part 1. The electric current is going through both bulbs at the same time, so disconnecting one does not affect the other. (This is how the Christmas lights you wish you had bought are wired.)

④⑤ Again, the circuit may be series or parallel.

Series   **Parallel**
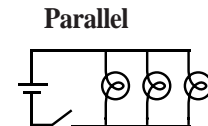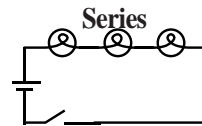
These circuits have the same characteristics as the ones in part 2-3

⑥ There are two ways of doing this as well.

Parallel-in-Series   **Series-in-Parallel**
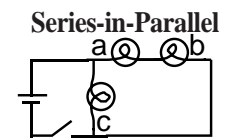
(The parallel portion of the first circuit will be very dim.)

What happens if you unscrew one of the bulbs depends on which bulb you unscrew. In the first circuit, unscrewing (a) will turn everything off. Unscrewing (b) or (c) will make (a) dimmer and leave the other one unaffected. In the second circuit, unscrewing (c) will make (a) and (b) brighter; while unscrewing (a) or (b) will make (c) brighter and turn the other one off.

⑦-⑩ Putting the batteries in series (2.1a) will make things the brightest, because then the voltage to the lights is the highest. Batteries in parallel (2.1b) will have the same effect as one battery. Batteries opposed (2.1c) will have no effect at all unless one of the batteries is nearly dead.

⑪ The potentiometer, when used this way, adjusts the brightness of the lamp. (For best results, use the batteries in series for this part of the lab.)

Exp 3- Ohm's Law

Procedure

②-⑥)Warn the students to be particularly careful when setting up the multimeter to measure current. Attaching an ammeter the wrong way can damage the meter.

Data Processing

Resistance	Current	Voltage	V/R	% difference
100	0.02	1.579	0.02	-1.87%
560	0.00	1.582	0.00	-2.73%
330	0.00	1.582	0.00	-3.32%
1000	0.00	1.583	0.00	-9.17%
10	0.14	1.549	0.15	-13.31%

Discussion

① Current is inversely proportional to R

② Yes. A curve fit of the graph above gives Current = 1.36 x Resistance$^{-0.98}$, which is quite close to the theoretical equation.
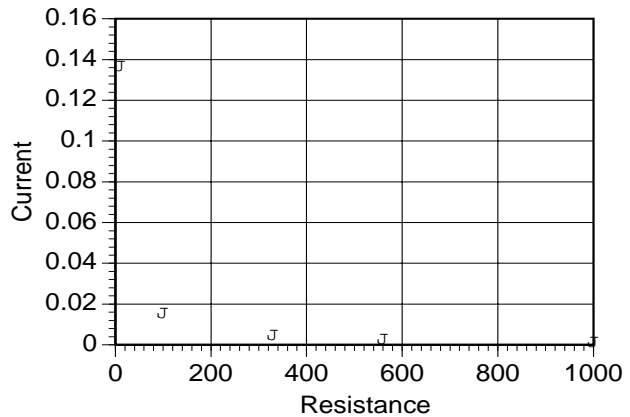
③) The greatest source of error is caused by the meter itself. Because the ammeter has some internal resistance, the measured current is less than the current when the meter is not there.

Exp 4- Resistances in Circuits

Procedure

①-④

	Colors	coded	measured	% error	tolerance
#1	brown-black-brown-gold	100	98.9	-1.10%	±0.05%
#2	brown-black-brown-gold	100	99.6	-0.40%	±0.05%
#3	brown-black-brown-gold	100	99.7	-0.30%	±0.05%

⑤ **Series**

$R_{12} =$ 198.3Ω
$R_{23} =$ 199.1Ω
$R_{123} =$ 298Ω

⑥ **Parallel**

$R_{12} =$ 49.7Ω
$R_{23} =$ 49.9Ω
$R_{123} =$ 33.3Ω
$R_{13} =$ 49.8Ω

⑦ **Combination**

$R_1 =$ 98.9Ω
$R_{23} =$ 49.9Ω
$R_{123} =$ 148.7Ω

⑧ **Series**

$R_{AB} =$ 428Ω
$R_{BC} =$ 891Ω
$R_{ABC} =$ 989Ω

Parallel

$R_{AB} =$ 76.1Ω
$R_{BC} =$ 207Ω
$R_{ABC} =$ 67.0Ω
$R_{AC} =$ 84.1Ω

Combination

$R_A =$ 98.9Ω
$R_{BC} =$ 207Ω
$R_{ABC} =$ 306Ω

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	Colors	coded	measured	% error	tolerance
A	brown-black-brown-gold	100	98.9	-1.10%	±0.05%
B	orange-orange-brown-gold	330	330	0.00%	±0.05%
C	green-blue-brown-gold	560	561	0.18%	±0.05%

Discussion

① The actual value matches the coded value much more closely than required by the tolerances.

②-④   In series, the resistances are added. $R = R_1 + R_2 + R_3 + ...$ In parallel, the reciprocals of the resistances are added. $1/R = 1/R_1 + 1/R_2 + 1/R_3 +...$ This is evidenced in all the data sets above.

Exp 5- Voltages in Circuits

Procedure

Equal Resistors:

Series

measurement	Resistance	Voltage
1	100	0.523
2	100	0.528
3	100	0.527
12	200	1.051
23	200	1.055
123	300	1.578

Parallel

measurement	Resistance	Voltage
1	33.33	1.565
2	33.33	1.565
3	33.33	1.565
123	33.33	1.565

Combination

measurement	Resistance	Voltage
1	100	1.049
23	50	0.529
123	150	1.578

Different Resistors:

Series

measurement	Resistance	Voltage
A	100	0.157
B	330	0.526
C	560	0.897
AB	430	0.685
BC	890	1.423
ABC	990	1.581

Parallel

measurement	Resistance	Voltage
A	67.49	1.574
B	67.49	1.574
C	67.49	1.574
ABC	67.49	1.574

Combination

measurement	Resistance	Voltage
A	100.00	0.509
BC	207.64	1.07
ABC	307.64	1.579

Discussion
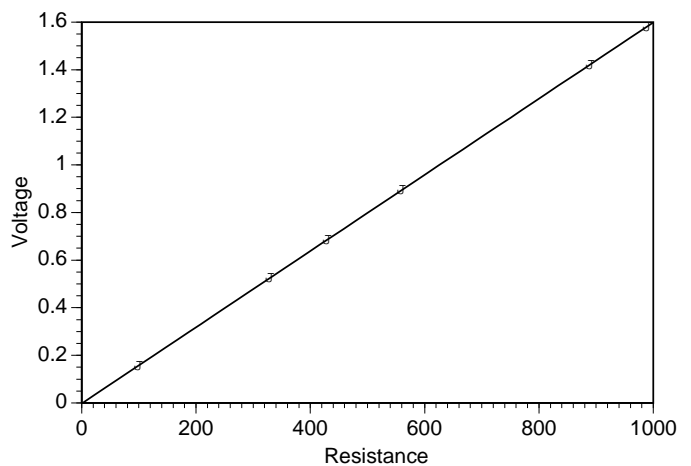
In any series circuit, the voltage is distributed according to the size of the resistors. (Notice that the graph above, of the data from the second series circuit, shows this direct relationship.)

In any parallel circuit, the voltage is the same across all elements.

In the combination circuit, the voltage acts as if the parallel resistors were actually one resistor, which is then in series with the first. The rules are the same.

Exp 6- Currents in Circuits

> ➤**NOTE:**   The resistors used were:
>
> $R_1 =$ 100Ω
> $R_2 =$ 330Ω
> $R_3 =$ 560Ω
>
> These are the same resistors as were used in the previous lab, and some of the data here originates in lab 5.

Procedure

Series:

The current was the same—1.5 mA—no matter where it was measured in the circuit.

Parallel:

Measurement	Resistance	Current	Voltage
1	100	0.0156	1.574
2	330	0.0047	1.574
3	560	0.0028	1.574
123	67.5	0.0229	1.574

Discussion

In any resistance circuit—series, parallel, or both—the voltage, current, and resistance are related by Ohm's Law:

$V = IR$

This pattern, and conclusion, should be apparent in student data.

> ➤**NOTE**:   The product of the resistances and currents obtained experimentally will generally be lower than the measured voltage. This is due to the non-zero resistance of the ammeter. When the meter is in the circuit, its own resistance lessens the current through that circuit. With most meters, this error should be less than 5% or so.

Exp 7- Kirchoff's Rules

Procedure

First circuit:
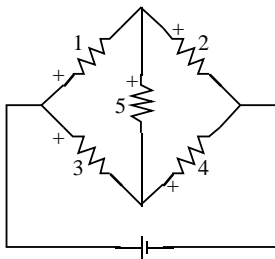
	R (Ω)	V (V)	I (mA)
1	100	0.40	3.9
2	560	1.17	2.0
3	330	1.05	3.1
4	100	0.52	5.1
5	330	0.65	1.9
T	216	1.57	7.1

Second circuit:
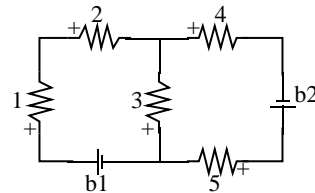
	R (Ω)	V (V)	I (mA)
1	100	0.27	2.6
2	560	1.50	2.6
3	330	0.19	0.5
4	330	1.07	3.2
5	100	0.32	3.2
b1		1.573	2.6
b2		1.588	3.2

Analysis

First circuit:

① node (1,3):   0.1 mA

   node (1,2,5):   0.0 mA

   node (3,4,5):   -0.1 mA

   node (2,4):   0.0 mA

② loop (1,5,3):   0.001 V

   loop (1,2,4,3):   0.001 V

   loop (5,2,4):   0.000 V

   loop (batt,1,2):   0.001 V

   loop (batt,3,4):   0.000 V

   loop (batt,1,5,4):   0.001 V

   loop (batt,3,5,2):   0.000 V

Second circuit:

① node (2,3,4):   -0.1 mA

   node (b1,3,5):   0.1 mA

② loop (b1,1,2,3)   0.001 V

   loop (b2,5,3,4)   0.001 V

   loop (b1,1,2,4,b2,5) 0.002 V

Discussion

Within the experimental uncertainty of the measuring device used (a DMM) Kirchoff's Rules are verified. The net current flowing into or out of any junction is approximately zero, and the sum of the voltages around any loop is approximately zero.

Exp 8- Capacitors in Circuits

Procedure

④ The rate at which the capacitor loses its charge depends on the impedance of the meter used to measure the voltage, as well as on the size of the capacitor. For this reason, most analog meters are not sufficient for this lab.

⑤
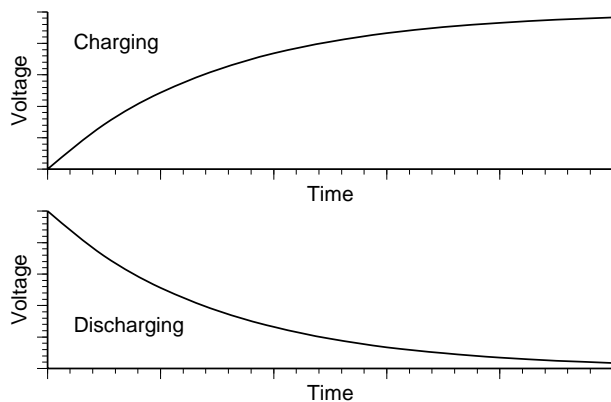
⑦ -⑪
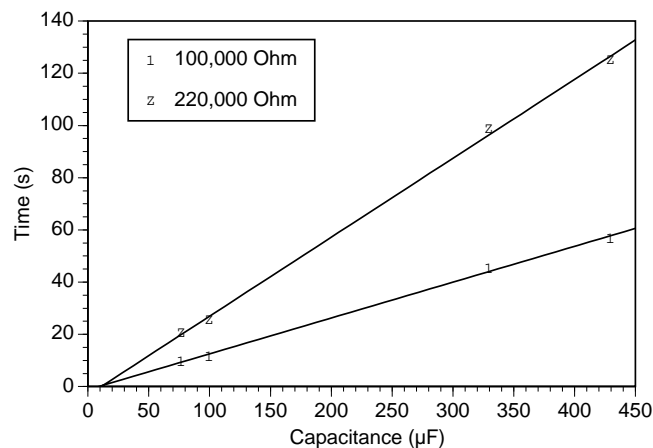
➤**NOTES**:
①② Charging: $t = -R\,C\,\ln(1 - V/V_o)$
 Discharging: $t = -R\,C\,\ln(V/V_o)$
 In either case, the time is linearly dependent on both resistance and capacitance.
③ Parallel: $C_p = C_1 + C_2$
 Series: $1/C_s = 1/C_1 + 1/C_2$

Exp 9- Diodes

Analysis
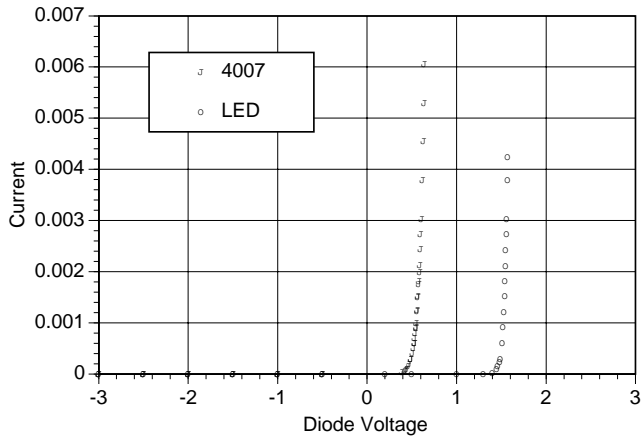
The diode acts as a one-way valve for electricity. Current can flow in one direction, but not in the other.

Extensions

① A zener diode would be similar to the 4007, except that there would be a breakdown point on the reverse biasing, beyond which the current would flow. This makes them useful for power regulation.

②) The LED opens up at a higher voltage than the 4007 (and it lights up).

Exp 10- Transistors

Analysis

②
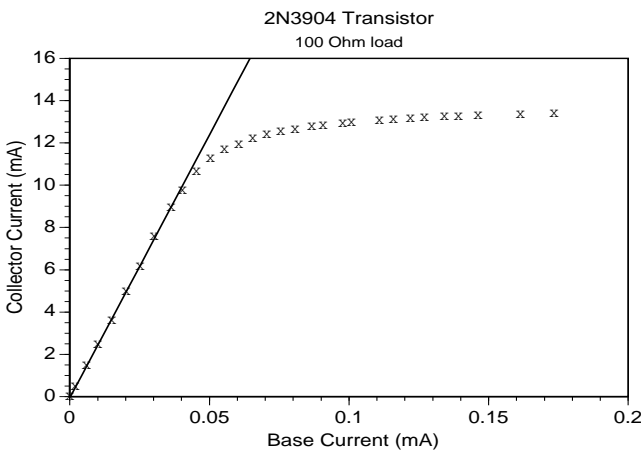
③ The linear region does not include the origin, due to the non-zero voltage that the junctions within the transistor require to turn on. (Similar to the effect in lab 9)

④ Beyond the "saturation point", the transistor is acting like a short circuit. It offers no resistance to the current; so beyond that point, there is no amplification. The current is limited only by the battery and resistor.

⑤ The current amplification of the transistor tested was 249. This value will vary from transistor to transistor; it's usually between 150 and 250 for the 2N3904 transistors supplied with the lab.

Discussion

① This graph shows the results of applying different values for R2. The amplification remains the same in each linear region, but the size of that linear region changes.
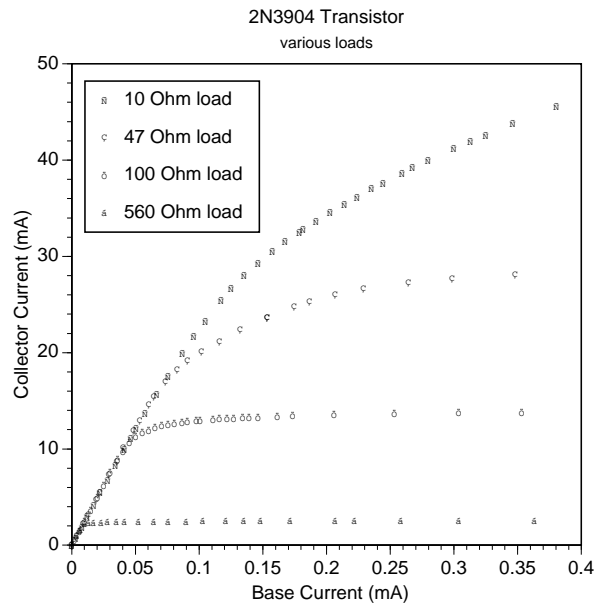
② The gain and/or saturation characteristics of the transistor will vary, although the basic shape of the graph will remain the same.

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Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Web: http://www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

 Title and Revision Date of software.

 Type of Computer (Make, Model, Speed).

 Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

 Title and Model number (usually listed on the label).

 Approximate age of apparatus.

 A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

 If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

 Part number and Revision (listed by month and year on the front cover).

 Have the manual at hand to discuss your questions.

*Instruction Sheet
for the PASCO
Model ES-9053A*

RESISTOR -CAPACITOR NETWORK

Introduction

The PASCO Model ES-9053A Resistor-Capacitor Network is designed for the study of RC time constants and for investigating capacitors connected in series and parallel. The RC time constants range from 25 to 200 seconds, so charging and decay curves can easily be investigated using an electrometer, such as the PASCO Model ES-9054B Student Electrometer, and a stopwatch.

Two resistors and three capacitors are wired into a switching network, which allows selecting three resistance values (50 MΩ, 100 MΩ, and 200 MΩ) in series with two selectable capacitance values (0.47 µF and .94 µF). A third capacitor (0.22 µF) can be selected in series or parallel with the other two capacitances.

The switches and external connections allow the following combinations:

- Six combinations of resistors and capacitors in series.
- Two combinations of capacitors in series.
- Two combinations of capacitors in parallel.

Three slide switches determine the component selection and circuit configuration (charging, discharging, or open circuit). The positions of these slide switches on the front panel diagram indicate the exact component values being used.
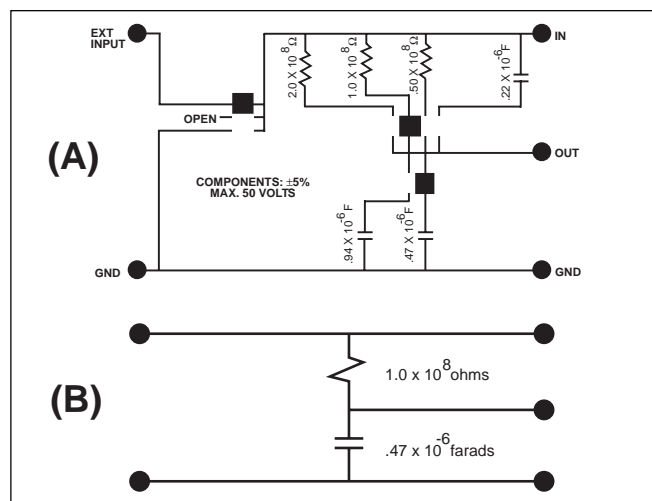
Figure 1: Switch Positions & Equivalent Circuit

Figure 1 (A) shows the slide switches in arbitrary positions, while Figure 1 (B) reflects the corresponding equivalent circuit diagram.

The three position slide switch on the left (S3) has a very useful OPEN position. It is often convenient to stop the charging or discharging process when making a measurement, and the OPEN position permits the circuit to be disconnected.

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Five binding posts allow a power supply, such as the PASCO Model ES-9049A Power Supply, and/or the electrometer to be connected at every possible component connection in the circuit.

> **➤IMPORTANT:** Never place more than 50 Volts DC across any component in the R-C network. When using the ES-9040A Power Supply, use the 30 VDC range only.

The experiment using the R-C network will give only suggested schematics, such as in Figure 1 (B)—and not specific switch settings.

Experiment:

Capacitors - Charging and Discharging

It takes a definite amount of time to charge or discharge a capacitor through a resistance. In this experiment we discover the relationships between capacitance, resistance, and the time required to charge the capacitor.

Equipment Needed:

 RC Network, DC Power Supply, and Electrometer.

The experimental circuits can be easily duplicated by tracing through the schematic on the front of the network and setting the switches accordingly. The battery in the experimental schematics is replaced with the DC Power Supply. Use the electrometer to measure voltages. DO NOT GROUND THE ELECTROMETER. (We want relative voltages.)

Procedure:

A. Charging Capacitors:

① Set up the circuit in Figure 2. At time **t = 0**, the switch is closed and capacitor voltage is recorded at regular time intervals. (A simple way to collect data is to open the switch at regular intervals and record the steady state reading. Why is this possible?)
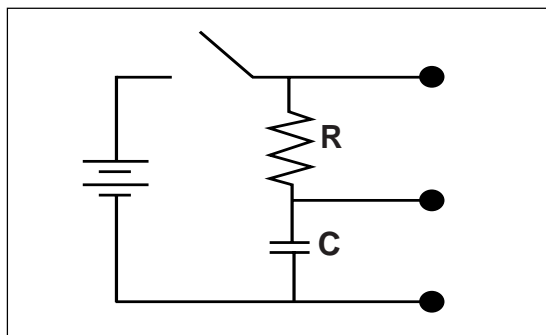

Figure 2

Plot time versus capacitor voltage for several values of R and C. What is the shape of the curve?

Let us define **T** as the time required for the capacitor to charge from 10% to 90% of its final value. What is the relation between **R**,**C**, and **T**? (Hint: Convert **R** to ohms, **C** to farads, and **T** to seconds.)

② Repeat the same experiment as in (1), but measure the voltage across **R** as a function of time. (This time opening the switch stops the current flow, hence steady-state readings cannot be made.)

According to Ohm's law, potential is proportional to resistance multiplied by current. Hence, the potential across the resistor is proportional to the charging current. What relation is there between the charging current and the charge on the capacitor? (Hint: Part (1) gives the relation between charge and time, whereas part (2) gives the relation between time and charging current.)

B. Discharging Capacitors:

① Set up the circuit in Figure 3. Charge the capacitor to an initial potential of 30 VDC. At time **t = 0**, close the switch and use the electrometer to measure the voltage across the capacitor. (Use the switch for steady state readings as in part A (1).
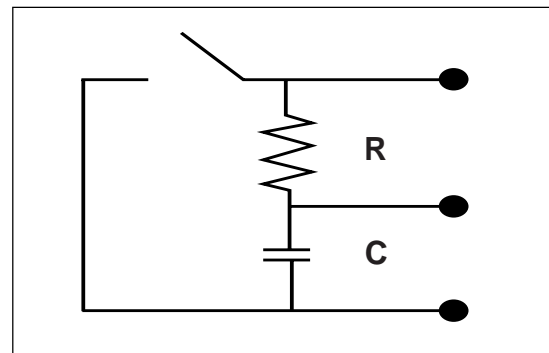

Figure 3

Repeat the experiment with several other values of **R** and **C**. Plot time versus capacitor voltage. Does the time constant (**T**) remain the same for discharging capacitors as it does for charging capacitors?

② Using the same circuit as in B (1), charge the capacitor to 30 VDC, and close the switch and measure the voltage across the resistor. Determine the relation between discharging current and capacitor potential.

Specifications

Resistance: Three selectable series values:
               50 MΩ, 100 MΩ, and 200 MΩ;
               ±5% Tolerance

Capacitance: Two selectable series values :
               0.47 µF and .94 µF;
               One series/parallel value:
               0.22 µF;
               ±5% Tolerance

Connections: Five external connections via banana
               jacks / binding posts allow electrical
   connections to each circuit node.

Component Selection: Via three slide switches

Repairs

Because of the extreme simplicity of the ES-9053A R-C
Network and the fact that each component can be tested
from the front panel, this section will only give a list of
replaceable parts. Although PASCO scientific will repair
the ES-9053A it is highly suggested that repairs be made
in the field. Any person with a basic understanding of
electronics is capable of making the necessary repairs.

Replacement Parts

PART REF.	DESCRIPTION/RATING
C1	Capacitor, Mylar, .22 mF, 100 V, ±5%
C2, C3	Capacitor, Mylar, .47 mF, 100 V, ±5%
R1, R2	Resistor, 100 MΩ, 3/4 W, ±2%
S1, S2, S3	Switch, Slide, 2 Pole, 4 Position
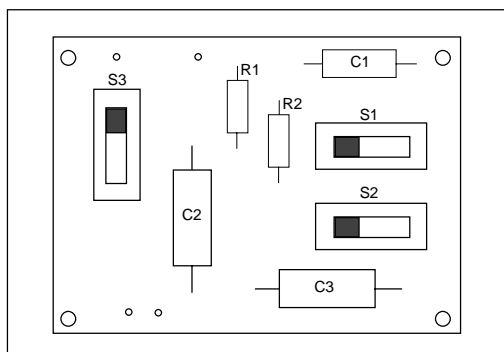
PCB Parts Layout

➤**NOTE:** Complete operational instructions of
other PASCO Electrostatic Accessories and direc-
tions for demonstrations possible with the complete
PASCO Electrostatic System are available in the
ES-9051 Accessory and Demonstrations Manual.
For a listing of available Electrostatic equipment
please refer to your current PASCO catalog.

Equipment Return

Should this product have to be returned to PASCO scien-
tific, for whatever reason, notify PASCO scientific by
letter or phone BEFORE returning the product. Upon
notification, the return authorization and shipping instruc-
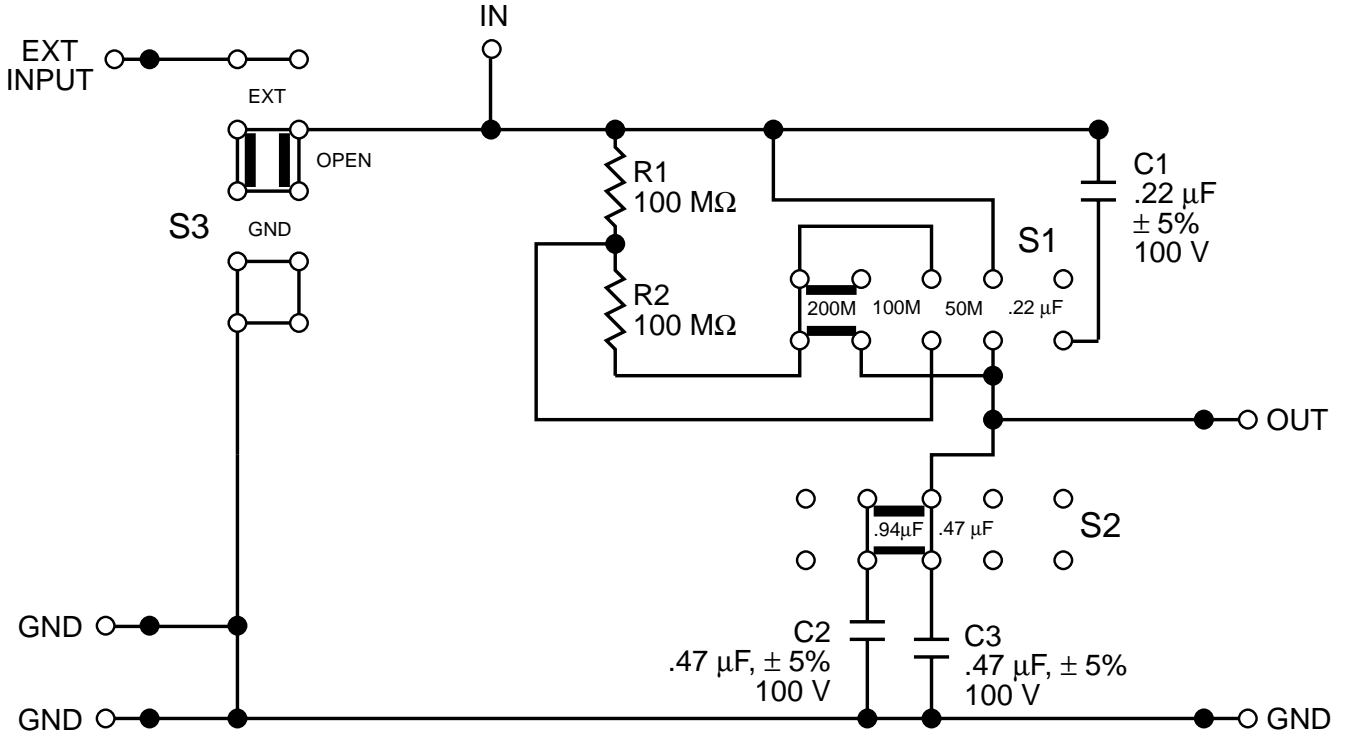tions will be promptly issued.

➤**NOTE:** NO EQUIPMENT WILL BE
ACCEPTED FOR RETURN WITHOUT
AN AUTHORIZATION.

When returning equipment for repair, the units must be
packed properly. Carriers will not accept responsibility
for damage caused by improper packing. To be certain
the unit will not be damaged in shipment, observe the fol-
lowing rules:

① The carton must be strong enough for the item
   shipped.

② Make certain there is at least two inches of packing
   material between any point on the apparatus and the
   inside walls of the carton.

③ Make certain that the packing material can not shift in
   the box, or become compressed, thus letting the instru-
   ment come in contact with the edge of the box.

Limited Warranty

PASCO scientific warrants this product to be free from
defects in materials and workmanship for a period of one
year from the date of shipment to the customer. PASCO
will repair or replace, at its option, any part of the product
which is deemed to be defective in material or workman-
ship. This warranty does not cover damage to the product
caused by abuse or improper use. Determination of
whether a product failure is the result of a manufacturing
defect or improper use by the customer shall be made
solely by PASCO scientific. Responsibility for the return
of equipment for warranty repair belongs to the customer.
Equipment must be properly packed to prevent damage
and shipped postage or freight prepaid. (Damage caused
by improper packing of the equipment for return ship-
ment will not be covered by the warranty.) Shipping
costs for returning the equipment, after repair, will be
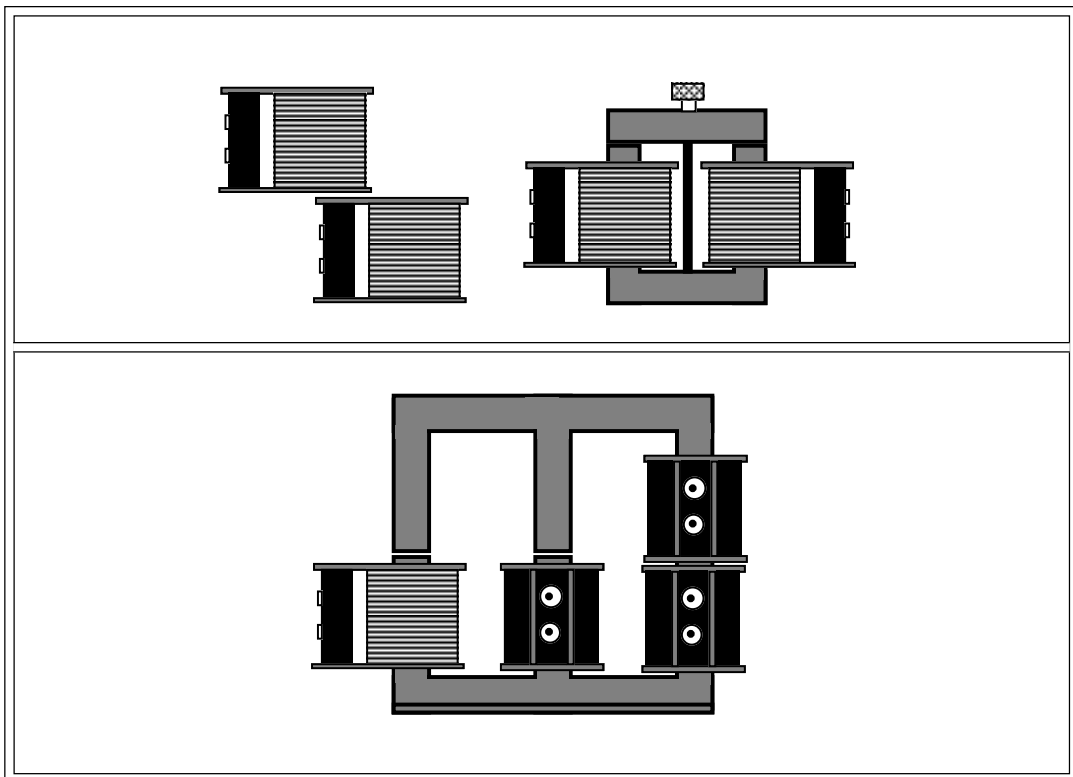paid by PASCO scientific.

ES-9053A
SCHEMATIC

Instruction Manual
and Experiment Guide
for the PASCO scientific
Model SF-8616 and 8617

COILS SET

$15.00

How to Use This Manual

The best way to learn to use the PASCO Basic Coils Set or the PASCO Complete Coils Set (referred to collectively as PASCO Coils Set) is to spend some time experimenting with it. We've organized this manual to get you started as quickly as possible. We strongly recommend that you read the Introduction and Experiments sections first. These are

followed by 4 experiments for your students to get started on. The experiments are ready to send to the copy room.

The Appendix contains technical data on the construction and operation of the coils.

Introduction

The PASCO scientific SF-8616 Basic Coils Set and SF-8617 Complete Coils Set provide necessary parts to experimentally investigate relationships involved with electromagnetism and electromagnetic induction. Coupled with a galvanometer, an accurate A.C. voltmeter, an A.C. ammeter, an oscilloscope and an A.C. power supply, little else is needed to carry out studies in this important area.

Additional equipment which is recommended includes small but strong magnets such as the ones found in the PASCO SE-8604 Bar Magnet Set, low constant springs, ring stands, a magnetic compass and iron filings.

One can study basic electromagnetism. The direction of the windings is shown on the top of each coil, allowing the relationship between current direction and the direction of the resulting magnetic field to be studied. See Figure 1.
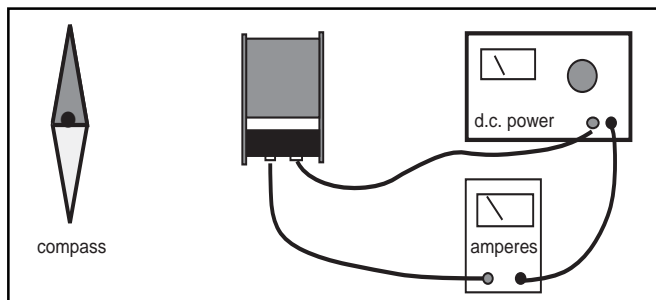

Figure 1

Using a coil from either kit, it is easy to demonstrate that a moving coil of wire near a magnet, or a moving magnet near a coil of wire will induce a voltage, and therefore a current. Simply move a magnet into the coil as shown in Figure 2, and a galvanometer will show a current flow.
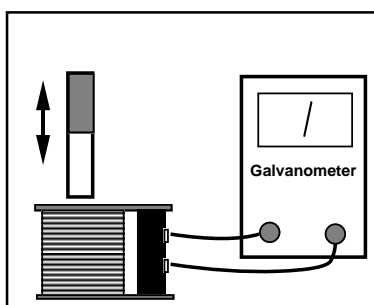

Figure 2

Moving the magnet back out will yield a current in the opposite direction. Reversing the magnet will reverse the relative currents, also. Leaving the magnet at rest inside the coil will produce no current. Thus, a change in relationship

between the magnet and coil is needed. The effect of moving slow versus moving fast can be demonstrated.

Finally, changing the number of coils of wire and repeating the process will complete an initial investigation. These investigations are generally semi-quantitative, focusing on relative sizes and directions. Another way to change the magnetic field is to provide an alternating magnetic field through the use of a second coil and an alternating current. See Figure 3.
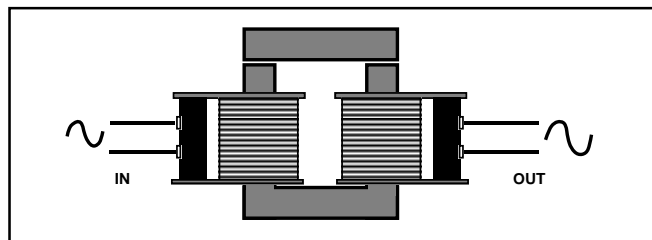

Figure 3

The Coils Set provides multiple coils and cores to experiment with this principle. These investigations lead to the basic relationships involved in transformers, and lead to more advanced studies of self- and mutual-induction.

With the addition of two magnets and small springs, a classic interaction of induced current and electromagnetic effects, plus simple harmonic motion, can be studied. See Figure 4.
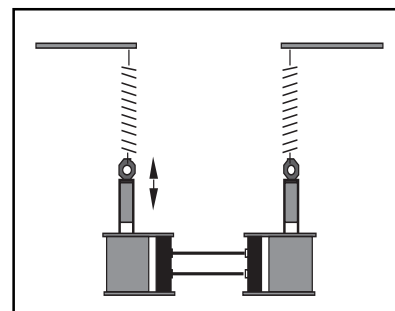

Figure 4

Suggested Experimental Approach

Demonstrate the basic principle of using the core and two coils to make a transformer. Show coils, core(s), supplies, loads, meters, etc. Have students develop areas of investigation and then proceed to carry them out. "Research teams" could investigate different factors and then combine their results for a comprehensive look at transformers.

Equipment Supplied

Your SF-8616 Basic Coils Set comes with the items shown in Figure 5a:

    a. (1) SF-8609 200-turn Coil

    b. (2) SF-8610 400-turn Coils

    c. (1) SF-8611 800-turn Coil

    d. (1) SF-8614 U-shaped Core

    e. (1) Manual

Your SF-8617 Complete Coils Set comes with all of the items in the SF-8616 Basic Coils Set along with the following additional items, as shown in Figure 5b:

    f.   (1) SF-8612 1600-turn Coil

    g. (1) SF-8613 3200-turn Coil

    h. (2) SF-8615 E-shaped Core

Figure 5a

Figure 5b

PASCO scientific
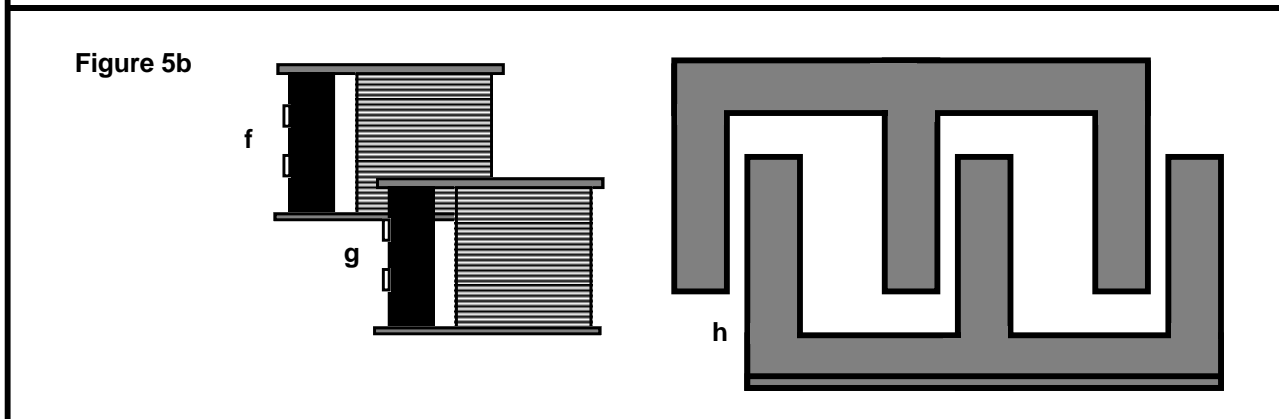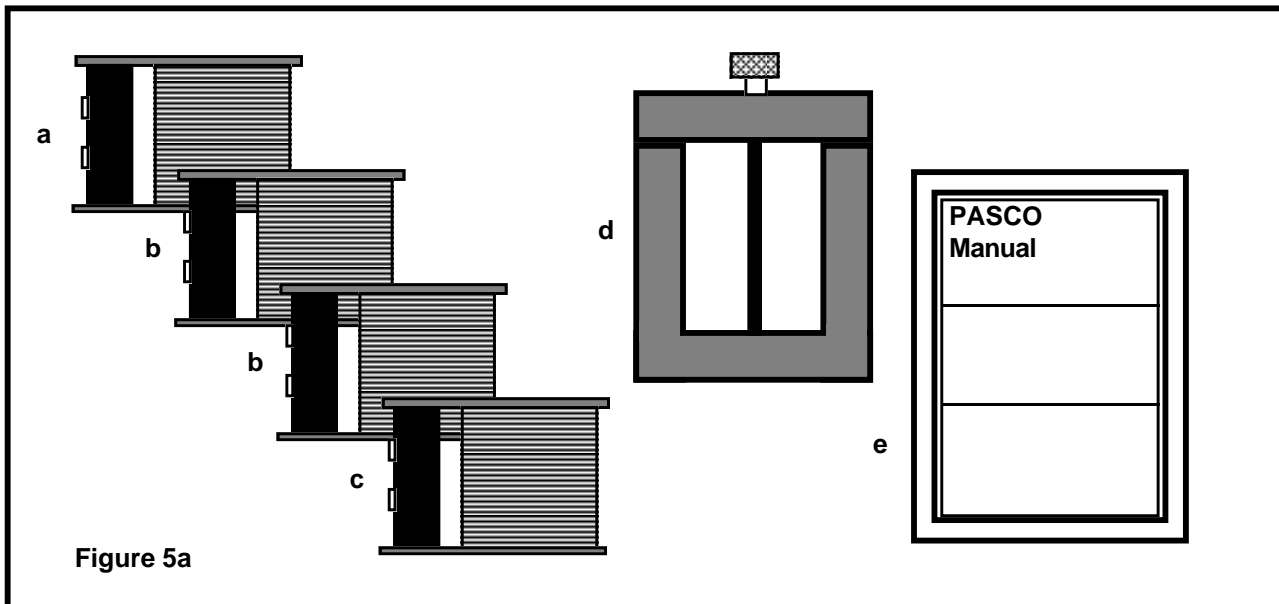
Experiments

Nature of Magnetic Field from an Electro-magnet

The coils from your PASCO Coils Set can be used in conjunction with a d.c. power supply or a battery to produce constant magnetic fields. Three possible experiments are shown below.
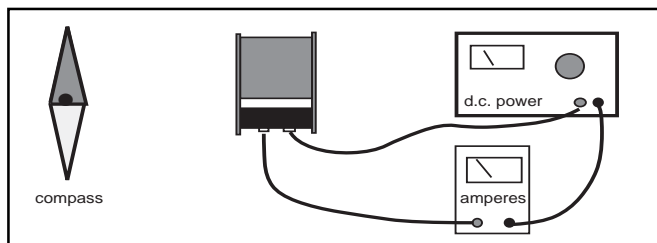

Figure 6

In Figure 6, a d.c. power supply is connected to the coil. A nearby magnetic compass is used to show the presence of a magnetic field and its direction. By noting the direction of the windings on the coil (See Figure 7), students can develop the rule for current direction and the resulting magnetic field direction. This experimental setup can be quantified, leading to a determination of how much current, through how many turns, is needed to produce a magnetic field equal to the earth's field. Specifics of the experimental design are left to the teacher and student.
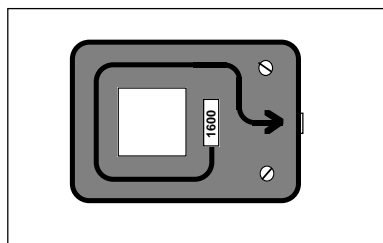

Figure 7

In Figure 8a and 8b, a coil is shown with its magnetic axis parallel to the table. A piece of cardboard is mounted so that it can be inserted into the center of the coil and extend beyond it on all sides. Iron filings are then sprinkled on the cardboard around the end of the current carrying coil. The magnetic field pattern can be quickly demonstrated.
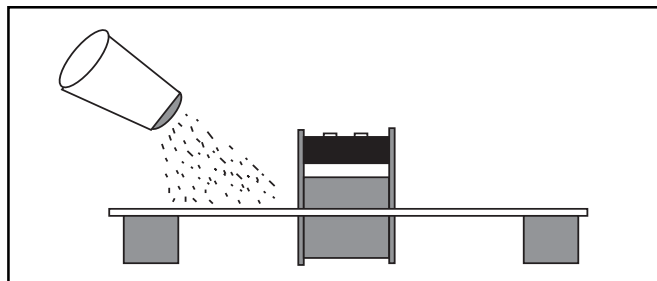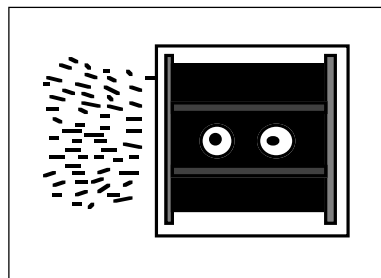

Figure 8a

Figure 8b

ALTERNATIVE: Small magnetic compasses can be used to probe around the coil to show its magnetic field.

Figure 9 shows a current carrying coil with a magnetic field inside. The cross-piece from the U-shaped Core is shown inserted in the coil, although the same experiment can be performed without the core. The strength of the electromagnet thus produced could be tested in a number of ways, including the use of the PASCO SF-8606 Digital Gauss/Tesla Meter. Note that the dramatic increase in magnetic field strength with the addition of a core can be clearly demonstrated.
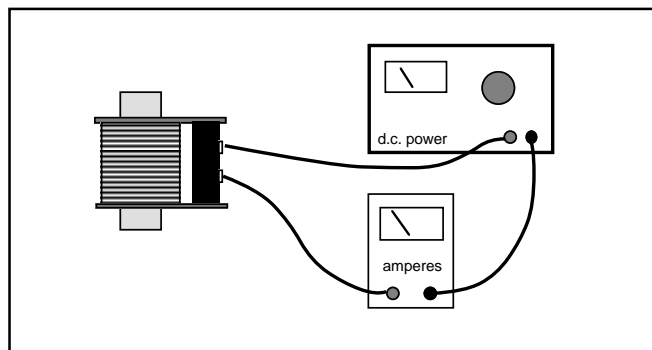

Figure 9

Solenoid

If the cross piece from the U-shaped Core is inserted into a coil, but not centered, it will be pulled into the coil when the alternating current is turned on. This demonstrates the basic action of a solenoid. In experiments with the 400-turn coil, a voltage of 8-10 volts A.C. was successful in demonstrating this principle. See Figure 10.
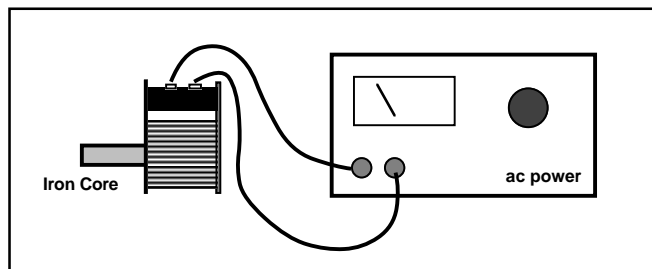

Figure 10

Electromagnetic Induction

Use a small, relatively strong bar magnet to demonstrate electromagnetic induction. It is only necessary to move the magnet up and down in the center of the coil. If the coil is attached to a galvanometer, the relative size of the induced current and the direction can be noted. See Figure 11.
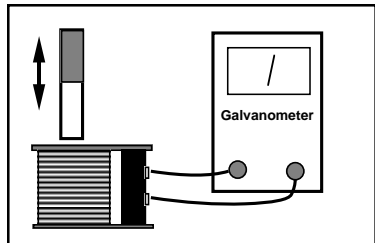

Figure 11

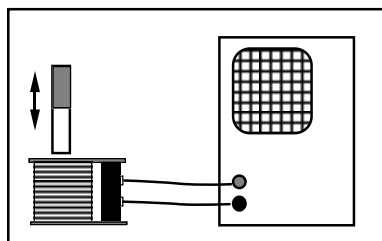A second way of showing the effect is to connect the coil to an oscilloscope. See Figure 12

Figure 12

> **NOTE:** A galvanometer shows the current produced, which should be proportional to the size of the induced voltage. Due to mechanical damping, galvanometers do not rise to the maximum value, but give useful semi-quantitative measurements of the maximum currents. An oscilloscope shows the size of the induced voltage directly, and gives a more instantaneous value.

The set-up below gives a method of "automatically" showing the induced voltage. A light spring which gives a nice simple harmonic motion with the attached magnet is needed. Note that the method of attaching the magnet is via a machine nut which is hooked to the spring and held by the magnetic field of the magnet. See Figure 13.
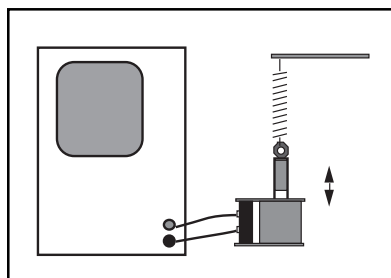

Figure 13

TRANSFORMERS

Leading directly to the study of transformers, the setup in Figure 14 allows students to see how induction can proceed by passing magnetic field between the two coils. Using air as the medium between the two coils, PASCO's experiments

showed a drop-off to an output voltage of less than 20% from the input voltage when the two 400-turn coils were used in this manner.
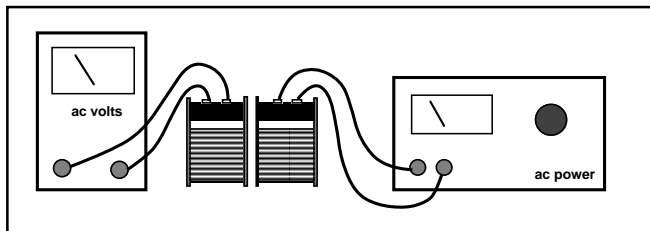

Figure 14

To improve the mutual induction, an iron core can be introduced. See Figure 15. Using the cross piece from the U-shaped core, the induced voltage increased to almost 50% of the primary voltage under the same conditions as above.
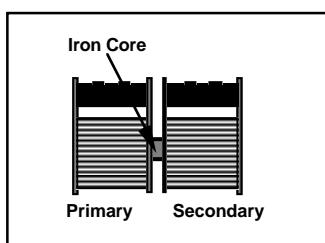

Figure 15

Numerous modifications of the cores which are provided can be investigated. In each case, the ratio of secondary voltage to primary voltage is noted. The variables in this situation thus become: Primary Number of Turns, Secondary Number of Turns, Existence of a Core, Shape of the Core, Primary Voltage, Primary Current, Secondary Voltage and Secondary Current. Students can be led on directed studies, or given the materials to develop their own experiments. Some possibilities are shown in Figure 16 below.
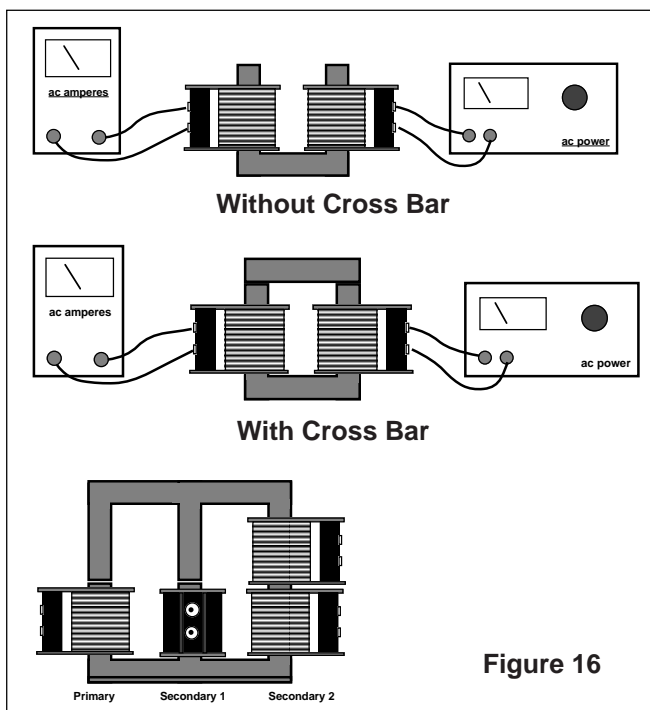

Without Cross Bar

With Cross Bar

Figure 16

Experiment 1: Transformer Basics I

Introduction

When an alternating current passes through a coil of wire, it produces an alternating magnetic field. This is precisely the condition needed for the electromagnetic induction to take place in a second coil of wire. In this lab you will investigate several of the factors influencing the operation of a transformer.

Equipment Needed - Supplied

1. The four coils from the PASCO SF-8616 Basic Coils Set
2. The U-shaped Core from the PASCO SF-8616 Basic Coils Set
3. Optional: the additional coils from the PASCO SF-8617 Complete Coils Set

Equipment Needed - Not Supplied

1. Low voltage ac power supply 0-6 VAC, 0-1 amp such as PASCO Model SF-9582
2. AC voltmeter 0-6 VAC
3. Banana connecting leads for electrical connections

Procedure

1. Set up the coils and core as shown in Figure 1. In the diagram, the coil to the left will be referred to as the primary coil, and the one to the right will be the secondary coil. Note that we are putting in an alternating current to the primary at one voltage level, and reading the output at the secondary.
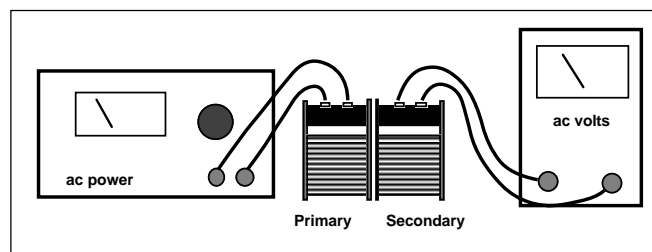

Figure 1

2. With the 400-turn coil as the primary and the 400-turn coil as the secondary, adjust the input voltage to 6 volts a.c. Measure the output voltage and record your results in Table 1.1.

3. Repeat step 2 after inserting the straight cross piece from the top of the U-shaped core. Record your results. (See Figure 2.)
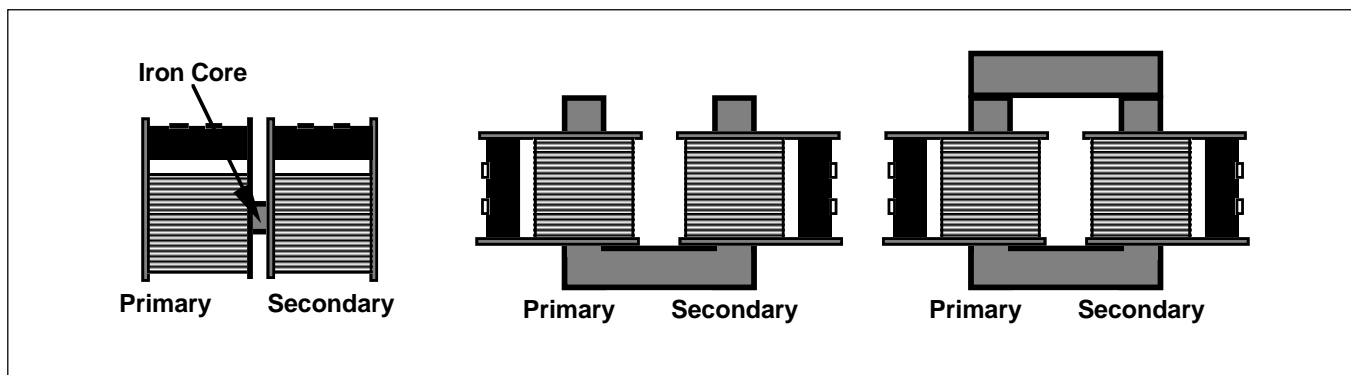
Figure 2

4. Repeat step 2 after placing the coils on the sides of the open U-shaped core. Record your results.

5. Finally, repeat step 2 after placing the cross piece over the U-shaped core. Record your results.

6. Using the core configuration which gives the best output voltage compared to input voltage, try all combinations of primary and secondary coils. Use a constant input voltage of 6.0 volts a.c. Record your data in Table 1.2.

Analysis

1. Which core configuration gives the maximum transfer of electromagnetic effect to the secondary coil? Develop a theory to explain the differences between configurations.

2. From your data in table 1.2, for a primary having a constant number of turns, graph the resulting output voltage versus the number of turns in the secondary. What type of mathematical relationship exists between numbers of turns of wire and the resulting output voltage? Is the data ideal? Why or why not?

3. Consider further improvements to your transformer. What additional changes might you make to increase the transfer from one coil to the other?

Data and Calculations

Table 1.1

| Number of Turns | | | | |
Primary Coil	Secondary Coil	Input V	Output V	Core

Table 1.2

Core Configuration: _____

| Number of Turns | | | | |
Primary Coil	Secondary Coil	Input V	Output V	Core

Experiment 2: Transformer Basics II

Introduction

In this lab you will investigate several of the factors influencing the operation of a transformer. In Experiment 1, the output factor was voltage as measured when there was nothing connected to the secondary (infinite resistance). In this lab, you will investigate input and output currents, in addition to voltages, with normal sized resistances in the secondary circuit.

Equipment Needed - Supplied

1. The four coils from the PASCO SF-8616 Basic Coils Set
2. The U-shaped Core from the PASCO SF-8616 Basic Coils Set
3. Optional: the additional coils from the PASCO SF-8617 Complete Coils Set

Equipment Needed - Not Supplied

1. Low voltage ac power supply 0-6 VAC, 0-1 amp such as PASCO Model SF-9582
2. One or two AC ammeters 0-2 A
3. Three resistors: 10Ω, 2 Watt; 100Ω, 2 Watt; 1000Ω, 2 Watt
4. Banana connecting leads for electrical connections

Procedure

1. Set up the coils, core and 1000-Ω load resistor as shown in Figure 1. In the diagram, the coil to the left will be referred to as the primary coil, and the one to the right will be the secondary coil. Note that we provide an alternating current at the primary at one voltage level, and read the output at the secondary at possibly a different value.

Figure 1

2. With the 400-turn coil as the primary and the 400-turn coil as the secondary, adjust the input voltage to 6.0 volts a.c. With a load resistance of 1000 Ω connected to the secondary, measure the input current, the output voltage and the output current. Record your results in Table 2.1.

3. Repeat step 2 after connecting in a 100 Ω load resistance.

4. Repeat step 2 after connecting in a 10 Ω load resistance.

5. Finally, repeat steps 2-4 after changing the secondary coil. Continue changing the coils until you have tested all combinations of input and output coils.

6. Replace the secondary coil with a relatively large diameter wire (18-20 gauge) wound around the core 5-6 times. See Figure 2. Again set the input voltage to the primary at 6.0 vac. Connect the ammeter to this new secondary, measuring the current when the resistance is only that of the ammeter. With the ammeter disconnected, measure the output voltage.

Figure 2

7. If you have the SF-8617 Complete Coils Set, arrange the primary and secondary coils as shown in Figure 3. Run the same set of experiments you did in steps 2-4, collecting the same items of data.
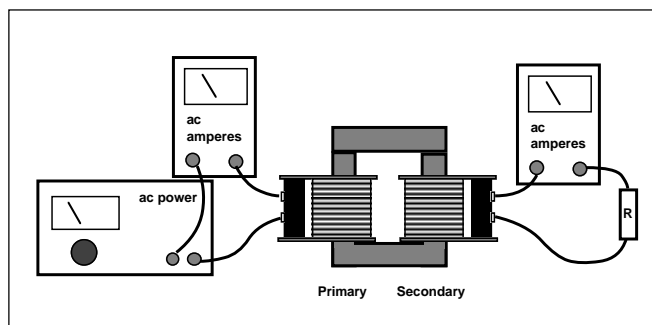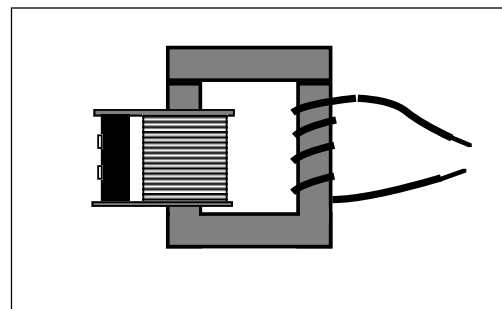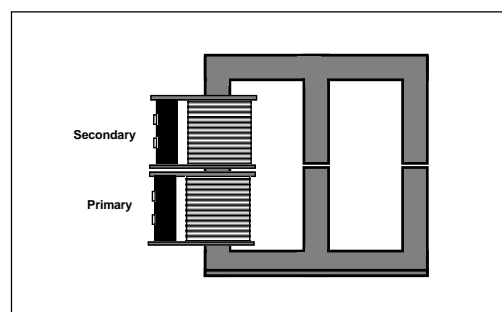

Figure 3

> Note: Other configurations can be investigated once you have the E-shaped core. At your instructor's direction, investigate other methods of arranging the primary and secondary coils.

8. If there are more than one PASCO Coils Sets in the laboratory, set up a series of transformers such as the one diagrammed below in Figure 4. Measure input and output voltages, input and output currents at various places in the chain. Keep careful track of your measurements and draft your observations based on these measurements.
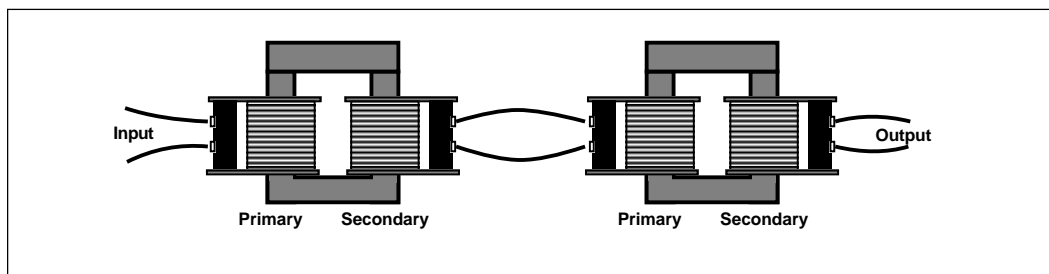

Figure 4

Analysis

1. Calculate the quantities asked for in Table 2.2. Note the suggestion at the bottom of the page. If you were able to carry out the modification in step 7, a separate data table should be constructed.

2. What relationship exists between the output current and the input current for different coils given a constant load resistance? How does varying the load resistance change the output current/input current relationship for a given combination of coils? Is the effect the same for all combinations? Elaborate and make an educated hypothesis on why your experiment behaved the way it did.

3. The ideal voltage gain is equal to the number of turns in the secondary divided by the number of turns in the primary. How did the actual voltage gain (Vout / Vin) compare to the ideal?

4. Ideally, transformers convert alternating current from one voltage to another with very little power loss (almost 100% efficient). Looking at your power gain (Pout / Pin), how did your transformers do compared to ideal transformers?

5. What combination of voltage and current is gained by having few coils of wire in the secondary? (step 6)

6. Analyze the behavior of the coils in the E-shaped core, and compare this to the U-shaped core. Is there a distinct advantage of one over the other? Why? Can an advantage gained be further enhanced by other changes? What might they be? (step 7)

7. If you began and ended with the same number of turns in your coils (step 8), how did the input and output voltages compare? How did the input and output power for the total combination compare? Were principles you experimented with previously in evidence during this part of the lab?

Data and Calculations

Table 2.1

Trial #	Number of Turns		Load R	Input V	Input I	Output V	Output I
	Primary	Secondary					

Table 2.2

Trial #	Input P	Output P	Voltage Gain	Power Gain

NOTE: It is recommended that the data collected above in Table 2.1 be gathered into a spread sheet program. Calculations of the input and output power, the voltage gain and power gain for Table 2.2 can quickly and easily be made using the spread sheet. Additionally, the data can be rearranged quickly to make it easy to analyze.

Notes:

Experiment 3: Springing into Electromagnetic Induction

Introduction

In this lab an interesting arrangement will allow you to investigate some of the subtelties of electromagnetic induction. The results will be qualitative, contrary to many of the labs you have done recently!

Equipment Needed - Supplied

1. The PASCO Model SF-8616 Basic Coils Set

Equipment Needed - Not Supplied

1. Two small, relatively strong magnets
2. Two springs with low force constants
3. Several machine nuts
4. Two ring stands
5. Banana connecting leads for electrical connections

Procedure

1. Set up the two 400-turn coils, the magnets, springs and ring stands as shown in Figure 1. See Figure 2 to see how the springs "attach" to the magnets.
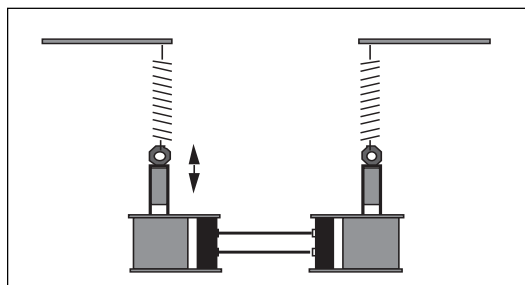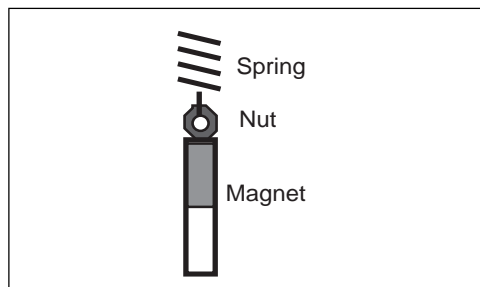

Figure 1

Figure 2

2. Move the magnet in one coil upward and then release it so that it sets up simple harmonic motion. Note the reaction of the second magnet. Can you arrive at an explanation as to why this is happening?

3. PREDICTION 1: What will happen if you reverse the leads in one of the two coils and repeat step 2? Try it to see if your prediction is accurate.

4. PREDICTION 2: What will happen if you were to use additional masses on one magnet, thereby increasing its period of SHM? Try this by adding several machine nuts onto the bottom of the magnet. Adjust the height of the ring stand as needed.

5. PREDICTION 3: What will happen if you were to use a different spring on one magnet?   Try it.

6. PREDICTION 4: What will happen if you use a different number of coils on one side?   Try it.

7. PREDICTION 5: What will happen if you insert another coil into the circuit, as shown in Figure 3? Try it. Does it make a difference if different coils are used? Try it.

8. PREDICTION 6: What will happen if you put a core into the third coil that you used in step 6? Why? Try it.
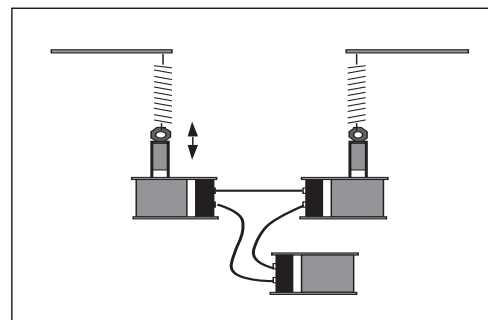

Figure 3

Analysis

1. Why did the magnets behave as they did? How does your observation relate to electromagnetic induction?

2. What was the effect of changing the polarity of the leads connecting the two coils? Why?

3. Why did the behavior change as a result of changing the mass of the magnet and/or the spring which was used?

4. Try to develop an explanation to cover the observations you made in steps 6-8. You may wish to begin considering energy!

Experiment 4: Intermediate Transformers

Introduction

In this lab you will continue investigating transformers. You will investigate additional core configurations and work into d.c. power supplies, one of the key applications of transformer technology.

Equipment Needed - Supplied

1. The PASCO SF-8617 Complete Coils Set

Equipment Needed - Not Supplied

1. Low voltage ac power supply 0-6 VAC, 0-1 amp such as PASCO Model SF-9582
2. AC voltmeter 0-6 VAC
3. AC ammeter 0-2 A
4. Oscilloscope
5. Two diodes 1 amp, 50 PIV (min) rectifiers such as 2N4007
6. Resistor 1000Ω, 2 Watt
7. Capacitor 470µF
8. Banana connecting leads for electrical connections

Procedure A

1. Set up the coils and core as shown in Figure 1. In the diagram, the coil to the left will be referred to as the primary coil, and the center one will be the secondary coil.

2. With the 200-turn coil as the primary and the 800-turn coil as the secondary, adjust the input voltage to 6.0 volts a.c. With a resistance of 1000 Ω connected to the secondary, measure the input current, the output voltage and the output current. Record your results in Table 4.1.

3. Now replace the 800-turn coil with the two 400-turn coils, stacked on the same arm of the E-shaped core. With the two coils connected as shown in Figure 2, with a load resistance of 1000 ohms, measure the input and output currents and voltages. Record your results in Table 4.1.

4. Reverse the leads to one of the coils and re-measure the currents and voltages. Record your results. How did the results compare with step 3? What did you change and why did you get the results you did?

5. Now move the two 400-turn coils to the third arm of the core. How do the values for current and voltage compare to those seen in the previous position of the coils? How would these values compare with a single 800-turn coil? Set up the single 800-turn coil and test your hypothesis.

6. Measure the individual voltages and currents of the 400-turn coils of the secondary when they are connected to the 1000-Ω resistance in the configuration which gave you the biggest output voltage and current. How do the two values compare with one another? Do they add or subtract to any specific values? Do the values you obtain in the experiment support your understanding of basic series circuits? Change the leads on one coil and re-measure the individual voltages and the total voltage. Why do you get your end result?
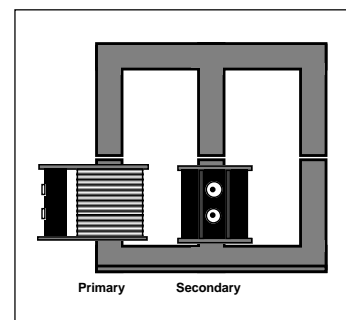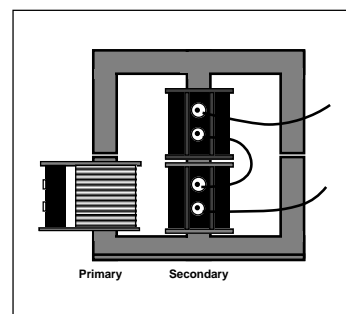

Figure 1

Figure 2

Procedure B

7. Set up the 200-turn coil as primary, and the 800-turn coil as the secondary. Put a diode into the circuit as shown in Figure 4, and leave the 1000-Ω resistor in as a load.

8. In this step, set the triggering of your oscilloscope to "LINE". This stabilizes the sweep so that it is sychronized with the a.c. line voltage. Now connect the ground lead (often a clip lead) from your oscilloscope to point A in Figure 3, and the probe to point B. Note the waveform. With the probe at point C, again note the waveform and also any differences between that and the one found at point A. How would you describe this difference?
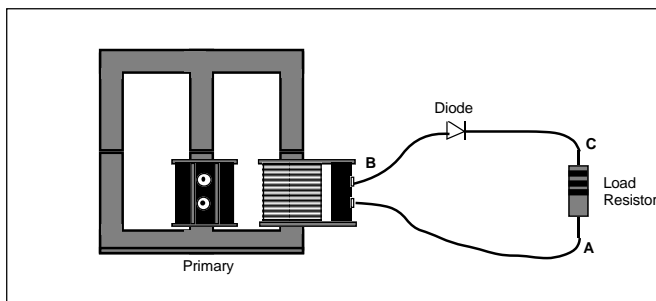

Figure 3

9. The waveform seen across the load resistance (A to C) is called a half-wave rectified signal. Half of the full sine wave passes through the diode, with the other half being blocked. This produces a directional current (d.c.) but one that is constantly changing in magnitude. To be useful, the voltage level must be made constant. The addition of an electronic "damper" should accomplish this.

10. Add the 470 µF capacitor as shown in Figure 4. What is the new waveform across the load resistor? Is it still varying as much as it did previously? What is the d.c. level of the resulting voltage?

11. Now change the 1000-Ω resistor to a 10-Ω resistor in the same circuit. How does this affect the waveform? How does it affect the d.c. voltage?
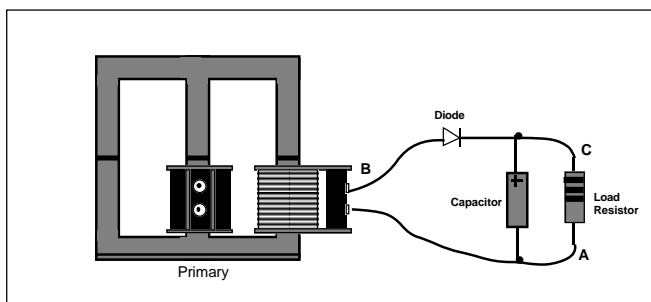

Figure 4

Procedure C

12. Now connect the two 400-turn coils so that they have maximum voltage and current output. With the 1000-Ω resistor as a load, connect the leads of the oscilloscope between points A and B as shown in Figure 5. What is the shape of the wave form? What is the waveform between points A and C? How does the size of the waveform between A and B compare to that between A and C?
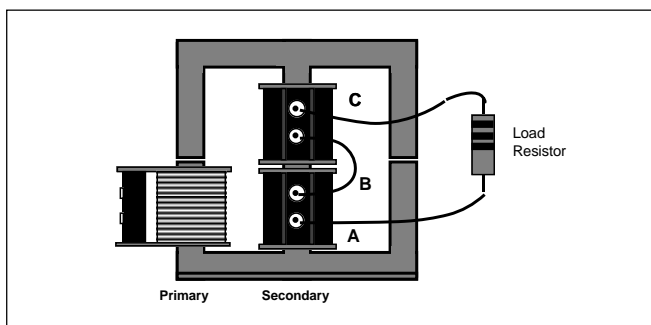

Figure 5

13. In this step, set the triggering of your oscilloscope again to "LINE". Connect the ground lead (often a clip lead) from your oscilloscope to point B in Figure 5. With the probe at point A, note the waveform. With the probe at point C, again note the waveform and also any differences between that and the one found at point A. How would you describe this difference?

14. Now we will make the difference in waveforms useful to us. Connect two diodes into your apparatus as shown in Figure 6. How does the waveform across the load resistance look? How does it differ from the waveforms you have seen in previous steps? Is this still alternating current, or is it directional (direct) current?

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15. The end result in step 14 is the production of a full-wave rectified signal, one which is directional in nature, although it varyies in amplitude over time. We will now add in a 470-µF capacitor as shown in Figure 7.

16. What is the new waveform across the load resistor? Do you have d.c., yet? What is the d.c. voltage you've produced?

17. Now replace the 1000-Ω load resistance with a 10-Ω resistor. What is the effect on the d.c. voltage compared to the 1000-Ω resistance? What is the effect on the waveform?
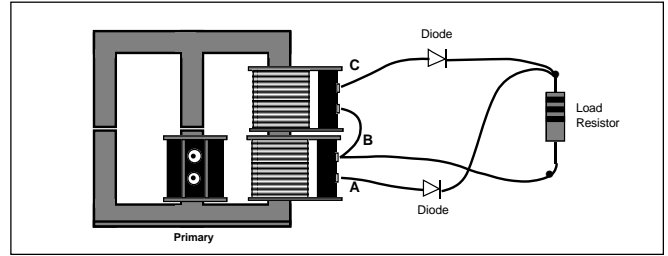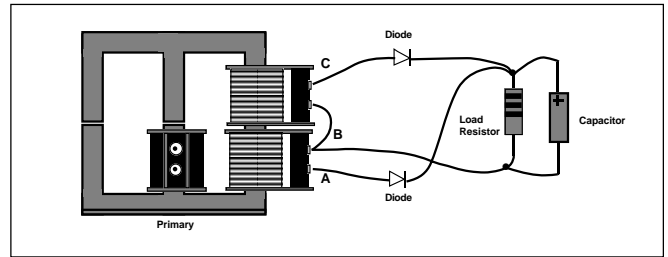

Figure 6

Figure 7

Analysis

1. Answer the questions which have been posed along the way during the procedure.

2. Why do you get such different results if you place the secondary coil(s) on the second or third leg of the E-shaped core? Think about the magnetic circulation that must take place within the core.

3. Compare the results of lowering the load resistance on a half-wave rectified circuit with lowering the load resistance on a full-wave rectified circuit. If you were to try to stabilize the output of a power supply, which would be better, a half-wave or full-wave rectified signal?

4. This experiment has introduced the concept of transformers and power supplies. Further reading and experimentation can easily begin from here and lead to profitable new understanding.

Data and Calculations

Table 4.1

Number of Turns						
Primary	Secondary	Input V	Input I	Load R	Output V	Output I

Appendix

Technical Data

PASCO Part No.	Number of Turns in Coil	Wire dia. mm	Maximum Current rms Amperes	DC Resistance ohms	AC Impedance ohms		Self-inductance mH
					50 Hz	60Hz	
SF-8609	200	0.9	2 A	0.6	0.64	0.65	0.67
SF-8610	400	0.65	1 A	2.2	2.4	2.5	3.2
SF-8611	800	0.45	0.5 A	7.7	8.7	9.1	13.5
SF-8612	1600	0.33	0.25 A	35.4	39	40.5	52
SF-8613	3200	0.22	0.125 A	151	164	170	207

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.

Instruction Sheet
*for the PASCO*
Model SF-8619

MAGNETIC DIP NEEDLE

Introduction

This compass needle is used to measure the dip angle of the Earth's magnetic field. However, it may also be used in its horizontal position as a conventional compass.

Setup Procedure

① Assemble the two parts of the dip needle by inserting the banana plug connector into the hole in the black rod on the stand, as shown in equipment setup diagram.
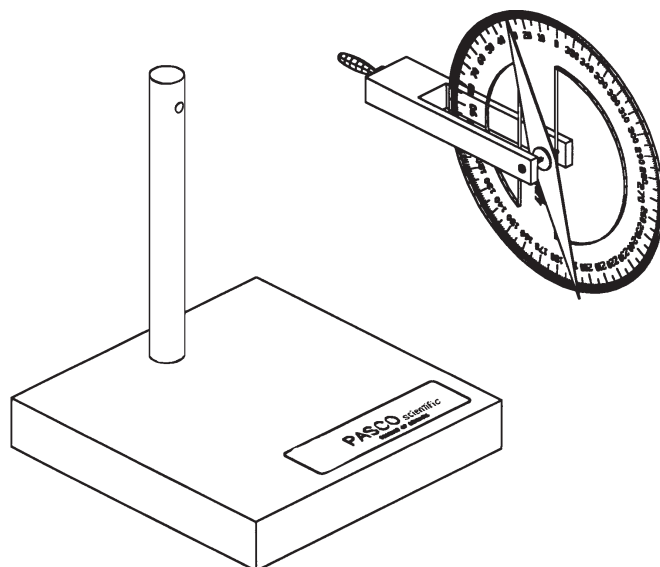
Equipment Setup

② Put the dip needle in a location which is far away from any ferromagnetic materials and other magnetic fields. If you place the dip needle on a table, be sure there are no ferromagnetic supports under the table top.

③ Rotate the dip needle at its banana plug connection until the plastic scale is in the horizontal plane.

④ While in the horizontal position, rotate the entire apparatus to align the compass needle with the axis of banana plug pivot.

⑤ Without changing the orientation of the base, rotate the dip needle at its banana plug connection until the plastic scale is in the vertical plane.

Theory

The dip needle is a magnetized steel needle which rotates around its center of mass. When no other magnetic fields are present, the dip needle will align itself along the direction of the Earth's magnetic field. The dip angle, or inclination, is the angle between the horizontal plane and the total Earth magnetic field. By convention, the dip angle is positive when pointing downwards.

The dip needle apparatus measures the angle, θ between the vertical plane and the total Earth magnetic field. In order to obtain the dip angle, subtract θ from 90˚.
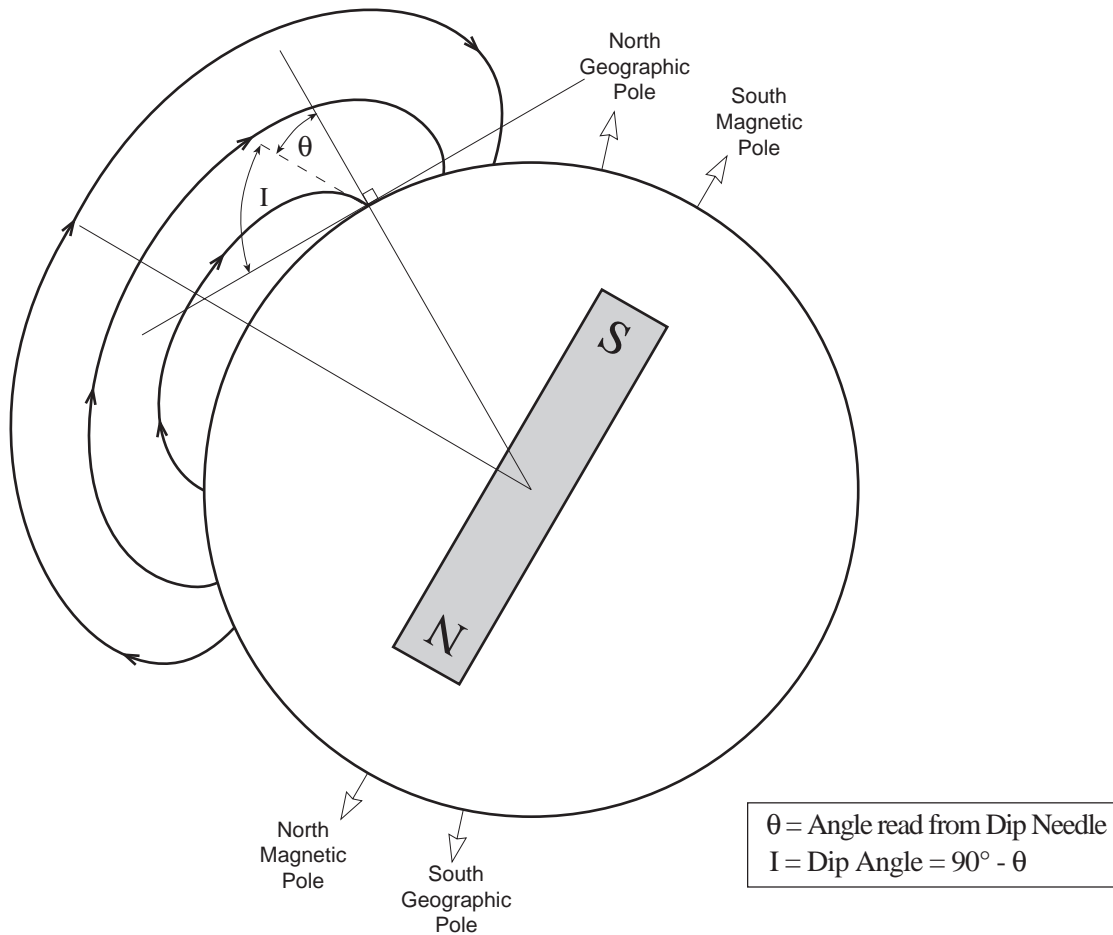
The United States Geological Survey maintains a public domain program for IBM compatible computers which models geomagnetic parameters including dip angle. The user inputs their latitude, longitude and elevation and the program calculates the dip angle. Copies of the program are free of charge and are available over the Internet via the following methods:

ftp host:	ftp.ngdc.noaa.gov	login anonymous
gopher host:	gopher.ngdc.noaa.gov	no login necessary
www host:	http://www.ngdc.noaa.gov	no login necessary

The appropriate file is pcgeomag.zip which contains the source code, executable and documentation files along with the current magnetic field model.

This instruction sheet written/edited by: Ann Hanks

North
Geographic
Pole

South
Magnetic
Pole

θ

I

S

N

North
Magnetic
Pole

South
Geographic
Pole

θ = Angle read from Dip Needle
I = Dip Angle = 90° - θ

Dip Angle for Northern California

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which is deemed to be defective in material or workman-
ship. This warranty does not cover damage to the product
caused by abuse or improper use. Determination of
whether a product failure is the result of a manufacturing
defect or improper use by the customer shall be made
solely by PASCO scientific. Responsibility for the return
of equipment for warranty repair belongs to the customer.
Equipment must be properly packed to prevent damage
and shipped postage or freight prepaid. (Damage caused
by improper packing of the equipment for return ship-
ment will not be covered by the warranty.) Shipping
costs for returning the equipment, after repair, will be
paid by PASCO scientific.

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*Instruction Sheet
for the PASCO
Model ES-9042A*

FARADAY ICE PAIL

Introduction

The Ice Pail designed by Faraday is an excellent product for sampling a charge distribution. It operates on the principle that a charge placed inside a conducting surface will induce an equal charge on the outside of that surface. For example, if a charged ball were hung inside a coffee can, the charge on the outside of the can would equal the charge of the ball. The charge can be measured with an electrometer such as the PASCO Model ES-9054B Student Electrometer.

The PASCO Model ES-9042A Faraday Ice Pail is a wire mesh cylinder measuring 10 cm in diameter by 15 cm deep with a wire mesh bottom. It is mounted on three insulating rods along the outer edge of a wire mesh shield.
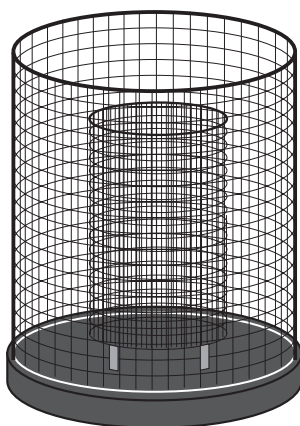
The wire mesh shield not only ensures complete visibility of the experiment but also helps eliminate the problem of stray charges and AC fields.

To prevent stray charges from producing erroneous results it is extremely important that the person performing the experiment be continually grounded while performing the experiment. The Ice-Pail needs to be temporarily grounded prior to starting the experiment.

A charged object such as the PASCO Model ES-9057A Charge Producers and Proof Plane is placed in the grounded ice pail (without touching it), and the electrometer indicates the potential between the ice pail and ground. The greater the charge the greater the potential. Thus we can easily measure relative charges by varying the charges in the ice pail and observing the potential indicated by the electrometer.

Complete instructions for the operation of PASCO Electrostatic equipment can be found in the ES-9051 Accessory and Demonstration Manual (included with the Demonstration System) and the ES-9055 Laboratory Manual (included with the Electrostatic Laboratory System)
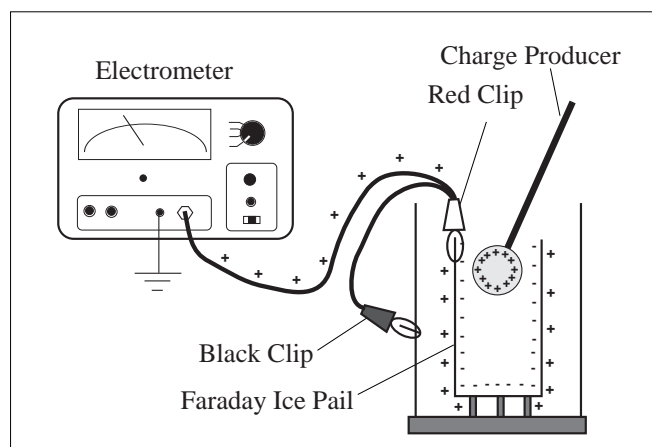

Figure 1

Demonstration: Faraday Ice Pail and Charge Production

Since the Faraday Ice Pail is used so frequently in electrostatic demonstrations, one should examine the relationship between the charge induced on the ice pail by an inserted object and the actual charge on that object. Using the ice pail, one can then investigate the nature of charging an object by contact as opposed to charging by induction.

Equipment needed: Faraday Ice Pail, charge producing objects (such as ES-9057A Charge Producers), electrometer

Setup

① Connect the electrometer input lead (red alligator clip) to the ice pail to create a system for measuring charge. The electrometer ground lead (black alligator clip) attaches to the shield. (Setup is shown in Figure 1.) Adjust the sensitivity of the electrometer so that most readings appear in the upper 2/3 of the scale.

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② Ground the ice pail (i.e., connect the inner pail to the shield) by touching the inner pail and the outer shield at the same time with the finger of one hand. (See Figure 2) While conducting the experiment it may be convenient to continually rest one hand on the upper edge of the shield. This also grounds the experimenter, providing the electrometer is connected to both ground and shield and it allows the ice pail to be easily grounded whenever necessary.
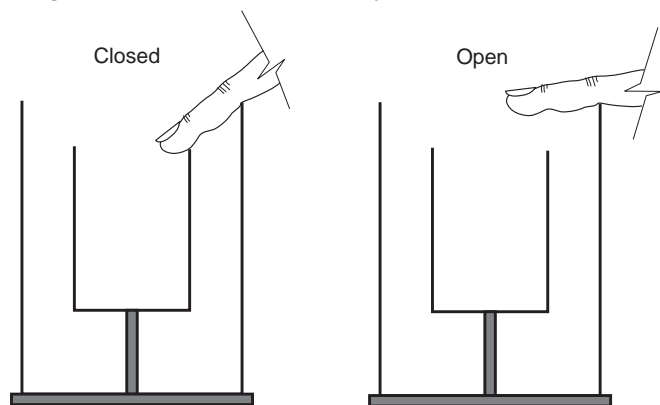

Figure 2

> ➤ **NOTE:** When removing your finger from the inner pail after grounding it, make certain that you are still touching the outer shield. *DO NOT* remove your hand from the shield before releasing the inner pail, as this sequence will not effectively ground the inner pail.

③ Make sure the electrometer reads "zero", indicating that there is no charge on the ice pail.

Procedure A

① Rub two charge producers together to create a charge on them.

② Insert one of the wands into the ice pail but do not let it touch the pail. Note the electrometer reading.

③ Remove the object from the pail and again note the electrometer reading.

④ Insert the wand again, allow it to touch the ice pail and then remove it. Note the electrometer reading.

⑤ Momentarily ground the ice pail and then touch the object to the pail again. Note the electrometer reading. Does any charge remain on the object?

What is the conclusion about the induced charge on the ice pail, as compared to the charge on the charge producer?

➤ **NOTE:**

① The charged object must be inserted at least into the lower half of the ice pail. Try inserting it, for example, approximately one centimeter below the top of the pail and attempt to explain your results.

② There may be a small charge retained on the exposed plastic between the aluminum disk and the aluminum rod on the charge producers. This residual charge does not transfer readily when the disk is touched to the pail. Therefore, (before starting the experiment) breathe on the exposed plastic of the charge producer so that the moisture in your breath will tend to remove any residual charge.

Procedure B

① Starting with initially uncharged charge producers, rub the blue and white materials together. Using the Faraday Ice Pail, measure the magnitude and polarity of their charges. By using the results from Procedure A it is not necessary to touch the charge producer to the pail. What relationship exists between these charges produced by contact?

② Ground the charge producers and rub them together inside the ice pail. What is the reading on the electrometer. Remove one charge producer and note the electrometer reading. Replace this charge producer but remove the other and note the electrometer reading.

③ Ground the charge producers again. Rub the white material against the aluminum proof plane. Measure the magnitude and polarity of the charges. Now rub the blue material against the aluminum surface and record your measurements.

④ Construct a list of materials such that if a material lower on the list is rubbed against a material higher on the list, the charge on the higher listed material is always positive. Such a list is called an electrostatic series.

To Reach PASCO

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email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Instruction Sheet
for the PASCO
Model ES-9057A

Charge Producers and Proof Planes

Introduction

The ES-9057A Charge Producers and Proof Planes are electrostatic components for use with additional equipment from the PASCO Electrostatics System ES-9062A. The two charge producers are used to generate equal positive and negative charges by contact. The two proof planes can be used to measure charge density on a charged object.

The Charge Producers

White surface

Conductive disk (black)

Blue surface

Non conductive neck (white)
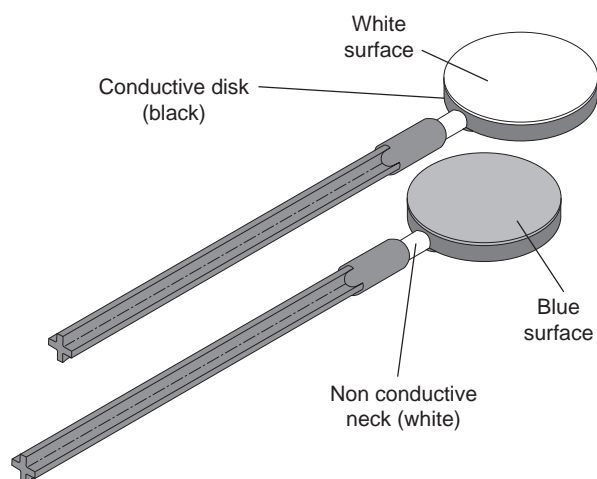
The charge producers consist of two wands, one with blue and one with white material attached to a conductive disk. Briskly rub the blue and white surfaces of the two charge producers together. The disk with the white surface will acquire a positive charge; the disk with the blue surface will acquire a negative charge. Rub the white surface of the one charge producer against one of the proof planes. The white disk will acquire a negative charge, while the other disk will acquire a positive charge.

> ➤ **NOTE:** Any build-up on the non-conductive neck can affect results. Clean with alcohol before using.

• If a zero charge is desirable, discharge the charge producers by touching the conductive disk and handle to ground. To be sure the disk and handle is fully discharged, gently breathe on the non conductive neck. The moisture from your breath will help remove any stray charge.

• Avoid touching the neck during normal use. The oils from your hands will provide a path for charges to leak off. Occasionally clean the disk surfaces and the neck with alcohol.

• When you first use the charge producers, or just after cleaning, they may not produce charges readily. Rub the white surface vigorously on the conductive proof plane disk.

> ➤ **NOTE:** The Charge Producers are designed to be used with an electrometer (ES-9054B). They do not produce sufficient charge for use with a standard electroscope.

The Proof Planes

The proof planes (set of two wands) are conductive disks attached to insulated handles. They are used to sample the charge density on charged conductive surfaces.

Conductive disk (black)

Non conductive neck (white)
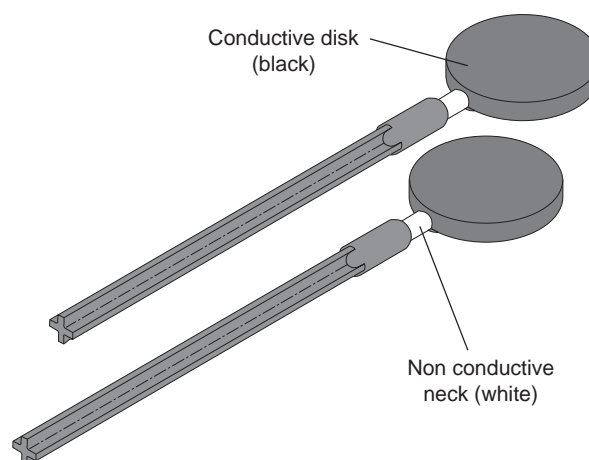
➤ **NOTE:** You can then use an electrometer and a Faraday ice pail (ES-9042A) to measure the charge density on the proof plane, as shown in the following illustration.


Faraday ice pail and shield
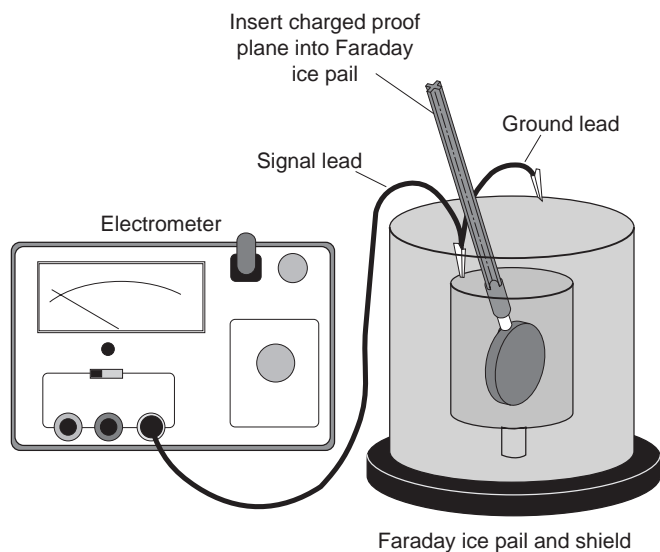
By touching the proof plane to a surface, it will acquire the same charge distribution as the surface. By measuring the charge on the proof plane, the charge density on the surface can be determined. The greater the charge on the proof plane, the greater the charge density on the surface where the proof plane made contact.

When the proof plane is touched to a conductor, the proof plane becomes part of the conductive surface. If the effect on the shape of the surface is significant, the sampling of the charge density will not be accurate. Therefore, always touch the proof plane to the conductor in such a way as to minimize the distortion of the conductive surface. The following illustration shows the recommended method for using the proof plane to sample the charge on a conductive sphere.

➤ **NOTE:** To accurately sample charge density, the conductor should be considerably larger than the disk of the proof plane and have a relatively large radius of curvature at the point from which the sample is taken. However, the proof planes can be used to test for charge polarity on conductors of any shape.
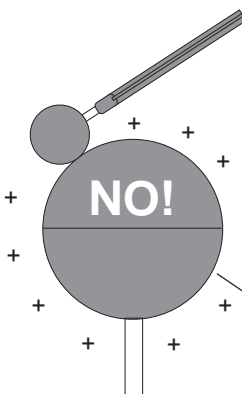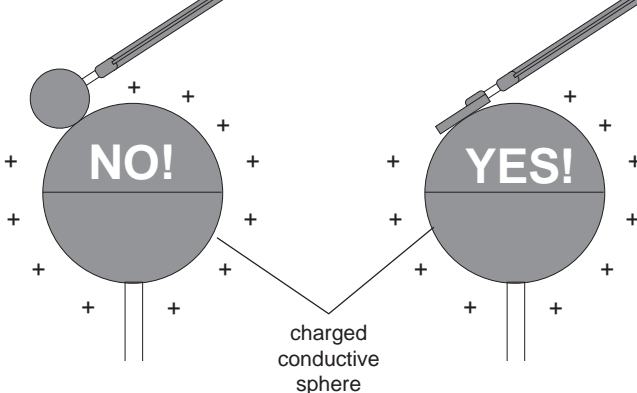
Other

The conductive disk material is carbon filled black polycarbonate (about $10^3\ \Omega$). The non-conductive neck is white polycarbonate (about $10^{14}\ \Omega$).

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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**Instruction Sheet
for the PASCO
Model TD-8550A**

THERMOELECTRIC CONVERTER

Introduction

The PASCO scientific Thermoelectric Converter consists of a thermoelectric heat pump sandwiched between two aluminum metal legs. Electric current from the thermoelectric heat pump can drive a small motor that has a fan attached to its shaft. The Converter can demonstrate the Seebeck effect (discovered in 1821). In this effect, a temperature difference across the thermoelectric heat pump gives rise to a current that drives the small motor ($\Delta T \to E$). For example, when one leg is in hot water and the other is in cold water, the small motor turns the fan. The Converter can also demonstrate the Peltier effect (discovered in 1834). When a current is passed through the thermoelectric heat pump, a temperature difference results ($E \to \Delta T$). One of the legs becomes warm while the other leg becomes cooler. Finally, the Converter acts as a "thermal capacitor". After a current is passed through the Converter to create the temperature difference ($E \to \Delta T$), flip the switch ($\Delta T \to E$), and the temperature difference causes a current that drives the small motor.
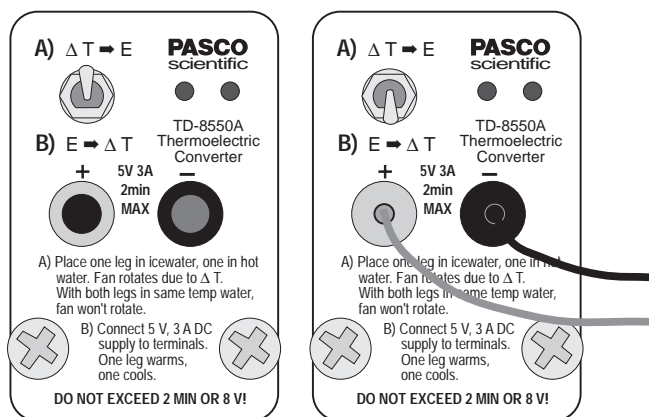

Figure 1 Switch Position

Figure 1 shows the top portion of the Thermoelectric Converter. Put the switch in the "up" position (toward

$\Delta T \to E$) in order to demonstrate the Seebeck effect (temperature difference causes electric current). Connect a source of electric current to the red and black banana jacks and put the switch in the "down" position (toward $E \to \Delta T$) to demonstrate the Peltier effect (current through the thermoelectric heat pump causes a temperature difference).

> ◗ **NOTE:** The recommended voltage and current is 5 Volts and 3 Amps (DC). ***Do not exceed 8 Volts.*** Do not run the 5 Volt, 3 Amp current through the device for more than <u>*2 minutes*</u>.

Equipment Needed:

- Cups for hot and cold water
- DC Power supply capable of 5 Volts and 3 Amps
- Patch cords

Recommended Equipment:

- TD-8556 Steam Generator
- SF-9584 AC/DC Low Voltage Power Supply or SF-9582 12 Volt AC/DC Power Supply
- SE-9750 and SE-9751 Banana Plug Patch Cords

Optional Equipment:

- Digital thermometer (such as PASCO Model SB-9631 or Model SE-9086)

Theory

A transformation whose only final result is to transform into work heat extracted from a source which is at the same temperature throughout is impossible.

Lord Kelvin

This was Kelvin's statement of the Second Law of Thermodynamics. The second law has been stated in many, seemingly unrelated ways; but in the end, all have been shown to be different ways of expressing the same basic principle. In its most general form, the Second Law tells us that no physical process will occur if it decreases the disorder—or *entropy*—of the universe. Conservation of energy, as expressed in the First Law of Thermodynamics, holds for every physical process. But many processes which would conserve energy do not occur. The Second Law describes this phenomenon.

OPERATION

Seebeck Effect:

The PASCO Model TD-8550A Thermoelectric Converter is designed to demonstrate this relationship between the First and Second Laws of Thermodynamics. The procedure used directly illustrates Kelvin's statement of the Second Law. The Converter is used as illustrated in Figure 2. Put the switch in the "up" position. One leg of the unit is placed in a cup of cold water and one in a cup of hot water. (Boiling water and ice water give good results.) Some of the thermal energy from the hot water is converted into work by the Converter, and the fan turns. Then the hot and cold water are mixed together in a larger container. Both legs of the unit are placed into the container. Now the fan does not turn.

The total internal energy of the water is not changed by mixing the hot and cold together, so there must still be sufficient energy in the water to turn the fan. But this would violate the Second Law of Thermodynamics, as stated by Kelvin.

> ➡ **NOTE:** As a further demonstration, place one leg in the mixed water (or in ice water) and one in a container of dry ice to demonstrate that there is energy available in the mixed water (and even in ice water).

This violation of the Second Law can also be explained in terms of entropy, using the expression $\Delta S = Q/T$, where ΔS is the change in entropy, Q is the heat transferred, and T is the temperature at which the heat is transferred. Considering only the heat transfer taking place in the cups of water, the following holds:
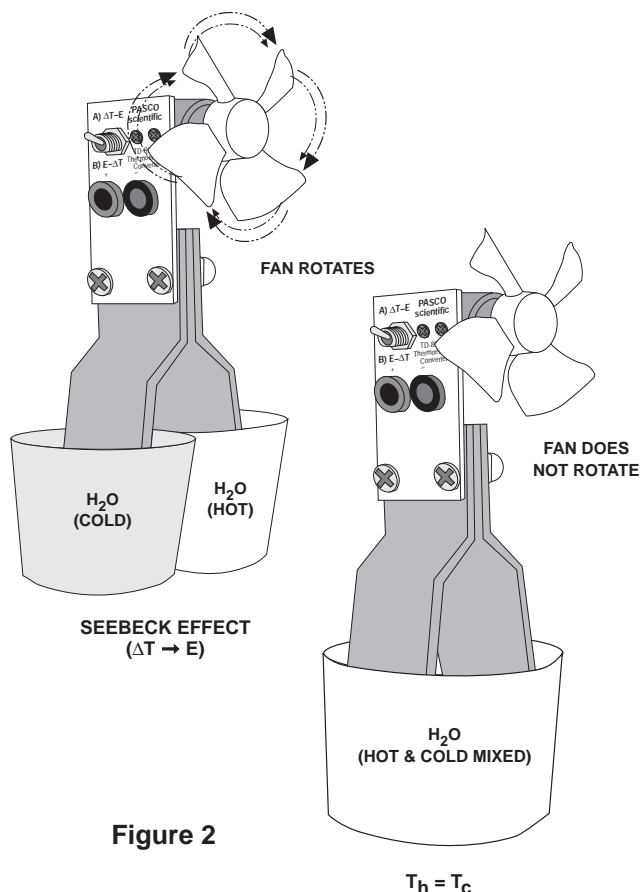

Figure 2

$T_h = T_c$

① The change in entropy of the hot water, $\Delta S_h = Q_h/T_h$, is negative, because of the heat transfer from the water into the Converter.

② The change in entropy of the cold water, $\Delta S_c = Q_c/T_c$, is positive, because of the heat transfer from the Converter into the water.

③ According to the second law, the total change in entropy, $\Delta S_T = \Delta S_c + \Delta S_h$, must be positive. Therefore, the process will only take place if $Q_c/T_c > Q_h/T_h$.

④ In order for the fan to be turned, some of the heat transferred from the hot water must be converted into work and will therefore not be available to be transferred back into the cold water. Therefore, whenever the fan turns, $Q_h > Q_c$.

⑤ The equations in steps 3 and 4 can only both be true if $T_h > T_c$. Once the water is mixed, however, $T_h = T_c$. Therefore, if the fan were to turn, it would violate the Second Law of Thermodynamics.

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Peltier Effect:

During the Peltier effect, a current through the thermo-electric heat pump of the Converter causes a temperature difference. Connect a DC power supply capable of 5 Volts and 3 Amps to the red and black terminals on the Converter. Put the switch on the Converter to the $E \rightarrow \Delta T$ (down) position . (***For this demonstration, you do not need to immerse the legs of the Converter in water.***) Turn on the power supply. In a few moments you should be able to feel the temperature difference of both aluminum legs of the Converter.

> ▶ **NOTE:** DO NOT LEAVE THE POWER SUPPLY ON FOR MORE THAN TWO MIN-UTES. DO NOT EXCEED 8 VOLTS.

As an optional exercise, begin with the Converter at room temperature. Measure the temperature of both legs. Then, while the current is applied to the Converter, use a digital thermometer to monitor the increase in temperature of the "hot" leg and the decrease in temperature of the "cold" leg.

SWITCH IS IN "DOWN" POSITION

TO POWER SUPPLY (5 VDC, 3 A) 2 min, 8 VDC MAXIMUM

HOT

COLD
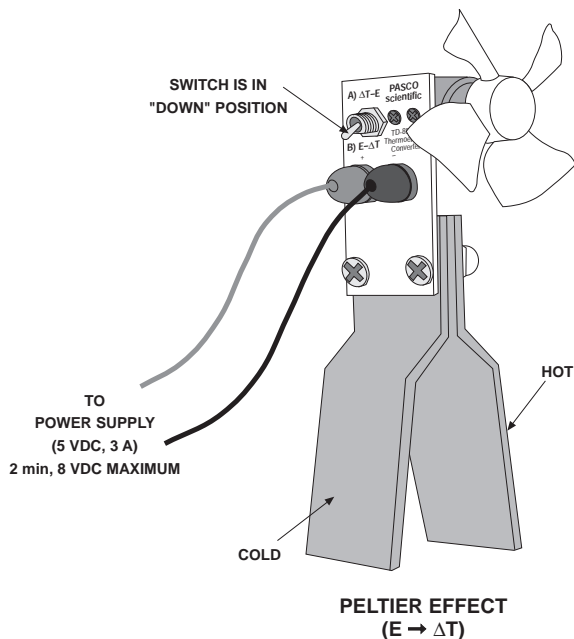
PELTIER EFFECT (E → ΔT)

Thermal Capacitor:

After demonstrating the Peltier effect, disconnect the power supply from the Converter. Put the switch to the $\Delta T \rightarrow E$ (up) position. The temperature difference caused when the current was applied to the thermoelec-tric heat pump will now cause the Converter to generate a current to drive the motor.

FAN ROTATES
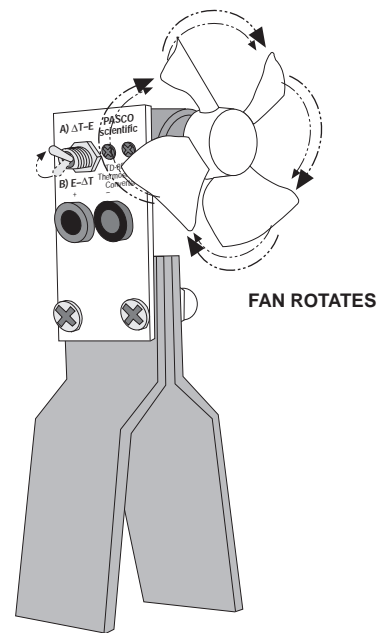
"THERMAL CAPACITOR" (MODIFIED SEEBECK EFFECT)

Description of Seebeck effect

The Thermoelectric Converter uses a series of thermo-electric cells to convert thermal energy into electrical energy that will drive the fan. Each cell is a semicon-ductor device. A simplified diagram of one cell is shown below.
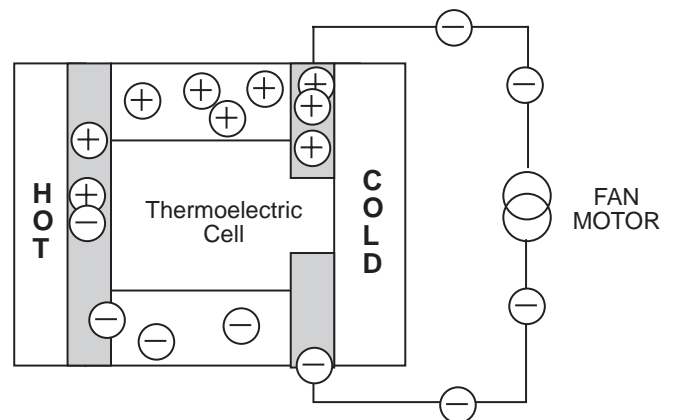
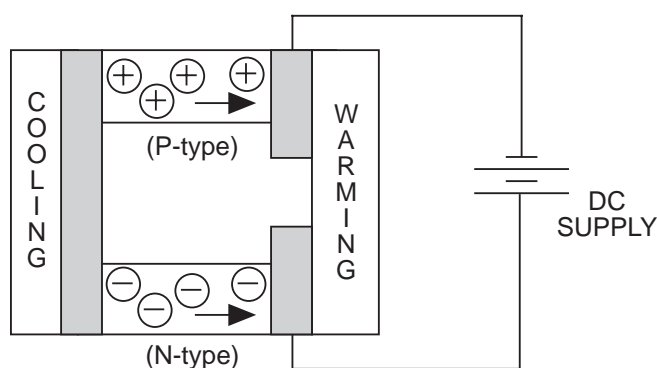**Thermoelectric Converter Cell (Seebeck effect)**

During the Seebeck effect, the heat entering the cell raises the energy level of some of the electrons in the cell. At the higher energy level, the electrons are no longer bound in the crystal structure of the semicon-ductor and are free to move. When they do so, they leave a vacant place, or hole, in the crystal. Lower energy electrons, though they can't move freely within the material, can jump from hole to hole. In this way, the holes can also migrate through the semiconductor material.

3

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The electrons migrate, as shown, through the N-type semiconductor material and the holes migrate through the P-type material. (N and P type materials are merely silicon that is "doped" with special impurities that enhance electron and hole migration.) The electrons flow through the external circuit and drive the fan motor. At the other end of the circuit they reenter the cell and encounter the holes of the P-type semiconductor. This occurs near the cold end of the cell. The electrons can therefore drop back into holes, giving up any excess energy they still retain as heat.

As long as the temperature differential is maintained between the two sides of the cell, the electrons and holes continue to migrate, and the fan continues to turn. However, if there is no temperature differential, the electrons can not recombine with the holes because there is no place to give up their excess energy. In this way, the thermoelectric cell is constrained by the Second Law of Thermodynamics.

Description of Peltier effect

During the Peltier effect, the electric potential difference causes electrons and holes to migrate from one end of the N and P type semiconductor material to the other. The movement of the electrons in the N type semiconductor results in a transfer of internal energy from that end of the semiconductor, and it cools. The same result occurs for the P type semiconductor during hole migration. The heat transfer from the "cold" leg to the "hot" leg is proportional to the carrier current passing through the circuit and the number of thermoelectric cells (couples) making up the thermoelectric pump.

Thermoelectric Converter Cell (Peltier effect)

Construction of the Thermoelectric Heat Pump:

The PASCO Thermoelectric Converter has 71 thermoelectric cooling "couples". These are made from two elements of semiconductor, primarily Bismuth Telluride (a quarternary alloy of bismuth, tellurium, selenium and antimony) heavily doped to create either an excess (N-type) or deficiency (P-type) of electrons. The

couples, connected in series electrically and in parallel thermally, are integrated into the thermoelectric heat pump. The heat pump is packaged between metallized ceramic plates.

Specifications:

When using the Thermoelectric Converter as a Peltier device, the power required to produce a given temperature difference depends on the temperature of the hot side. The hot side must never exceed 135 degrees C, the melting point of the solder which bonds the Bismuth Telluride ingots to the plates. Starting at 25 degrees C, the hot leg temperature increases much more than the cold leg temperature decreases (about 40 degrees versus about 8 degrees in 2 minutes). This is because the power dissipated by the hot side is the sum of the supplied power and the heat transferred from the cold side. (If the hot side is held to 25 degrees C, enough power can be applied to create a maximum temperature difference of about 67 degrees C.)

The resistance of the small motor is about 1 ohm.

Compatible PASCO Equipment

PASCO offers a complete line of laboratory and demonstration equipment for thermodynamics. Experiment quantitatively with the mechanical and electrical equivalents of heat, thermal conductivity, heat capacity, phase changes in water, and black body radiation.

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Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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