BUEHLER

Operation and Maintenance Instructions

BUEHLER®

ELECTROMET® 4

POLISHER/ETCHER

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BUEHLER® ELECTROMET® 4 Polisher/Etcher

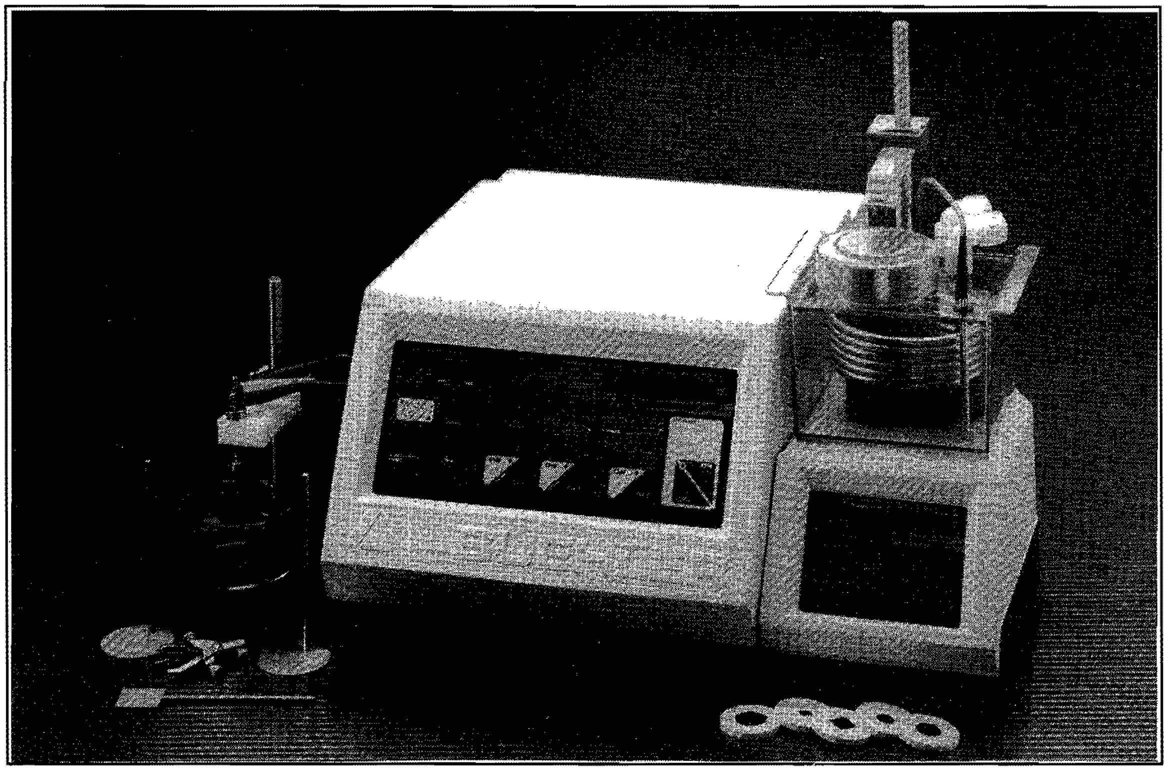


Figure 1. ELECTROMET® 4 Polisher/Etcher

Warranty

This unit is guaranteed against defective material and workmanship for a period of two (2) years from date of receipt by customer. Warranty is void if inspection shows evidence of abuse, misuse or unauthorized repair. Warranty covers only replacement of defective materials.

If, for any reason, this unit must be returned to our plant for warranty service, please apply for prior authorization with shipping instructions, and include the following information: Customer Purchase Order Number, Buehler Ltd. Invoice Number and Date, Serial Number, and reason for return.

Unpacking

Carefully unpack and check contents. If any components are missing or damaged, save the packing list and material and advise the carrier and Buehler Ltd. of the discrepancy.

Assembly

The ELECTROMET® 4 Polisher/Etcher is shipped as three units: the Power Source, the Polishing Cell and the Etching Cell.

Power Source

The Power Source is shipped fully assembled.

Polishing Cell

The Polishing Cell is shipped fully assembled except for the Support Post, Anode Arm and Cable which must be assembled and attached to the Cell Base. Figure 2 illustrates how various parts of the Polishing Cell are assembled. A set of five Masks is wrapped separately.

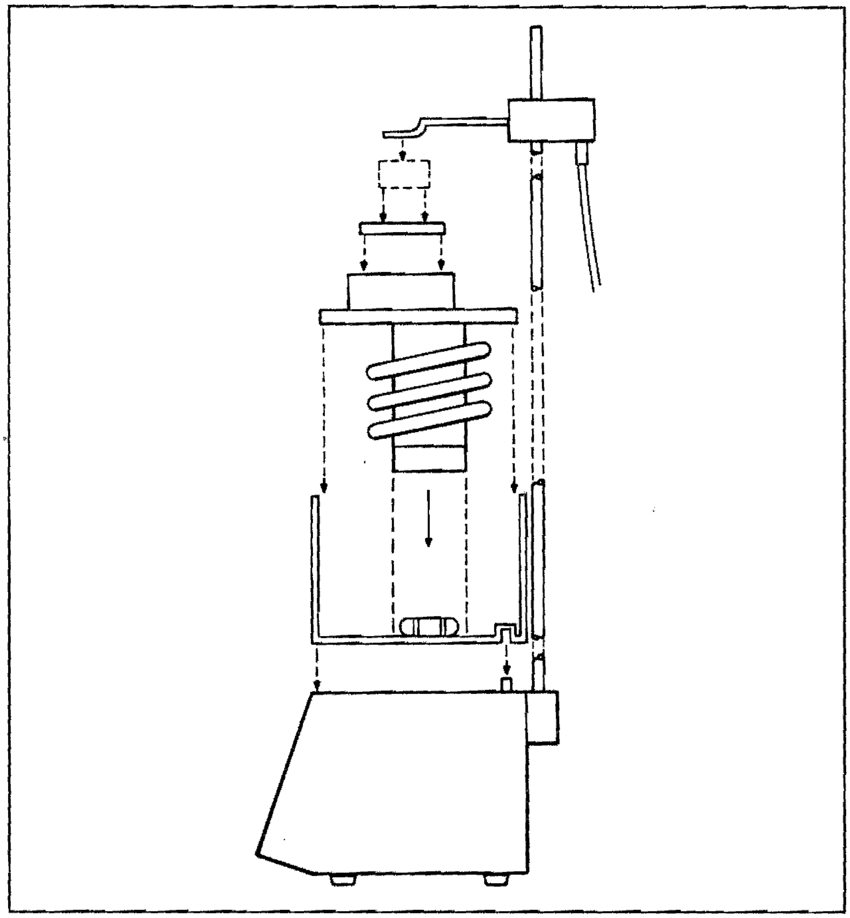


Figure 2. Polishing Cell Installation Detail

Etching Cell

The Etching Cell requires some minor assembly. First screw the Cell Post into the threaded hole in the Base; then slide the Arm Assembly over the Cell Post. Select either a Vertical or Horizontal Cathode, depending on the specimen to be etched. The Vertical Cathode is intended for mounted specimens and the Horizontal Cathode for those that are unmounted. For mounted specimens, electrical contact is made by means of the spring loaded Anode Rod which is part of the preassembled Arm Assembly. Unmounted specimens must be held by the Unmounted Specimen Clamp which is installed by sliding the open end of the Clamp Sleeve over the pointed end of the Anode Rod and tightening the thumb screw.

Installation

The ELECTROMET® 4 Polisher/Etcher should be installed in a convenient location near a chemical sink. **It is advisable to place the Polishing Cell and/or the Etching Cell within a chemical fume hood on an adjacent table.** For recommended ELECTROMET® 4 Polishing Cell layout, see Figure 3. For recommended ELECTROMET® 4 Etcher Cell layout, see Figure 4.

Electrical

POLISHING CELL (Figure 3): Connect the Polishing Cell Electrical Cable to the indicated outlet on the rear panel of the Power Source. Secure the connection by screwing the locking ring in a clockwise direction. Connect the temperature probe cable to the indicated outlet on the rear panel of the Power Source. Make sure that the Anode and Cathode Cables are plugged into their respective jacks in the Polishing Cell Base.

ETCHING CELL (Figure 4): Clamp the Positive (red) Clip to the Anode Rod and the Negative (black) Clip to the Cathode. Insert the Electrical Jack into the indicated outlet on the rear panel of the Power Source.

POWER SOURCE (Figure 3 and 4): Connect the Power Cord to an electrical outlet rated for the electrical service indicated on the Specification Plate on the rear panel. Position the white Selector Switch on the rear panel to the desired "Etch" or "Polish" mode.

Polishing Cell Plumbing (Figure 3)

The cooling system should be used at all times for reasons of safety as well as to assure uniform results. **A significant increase in temperature could alter the results and in extreme cases produce explosive conditions.**

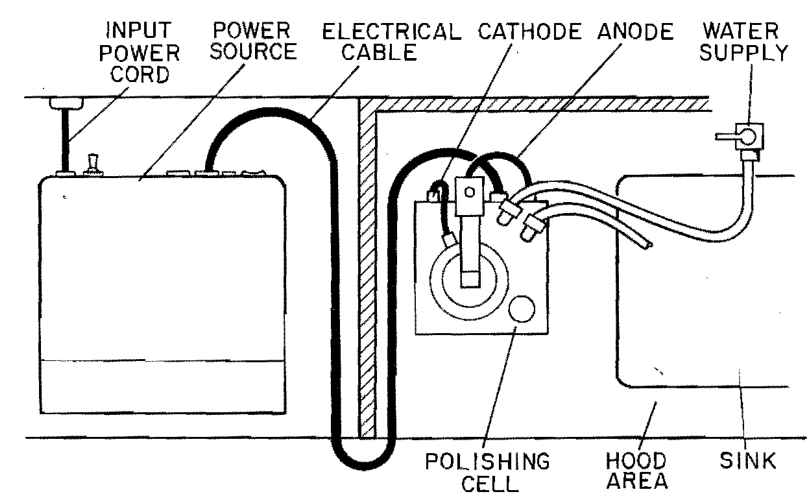


Figure 3. Layout for ELECTROMET® 4 Power Source with Polishing Cell (Top View)

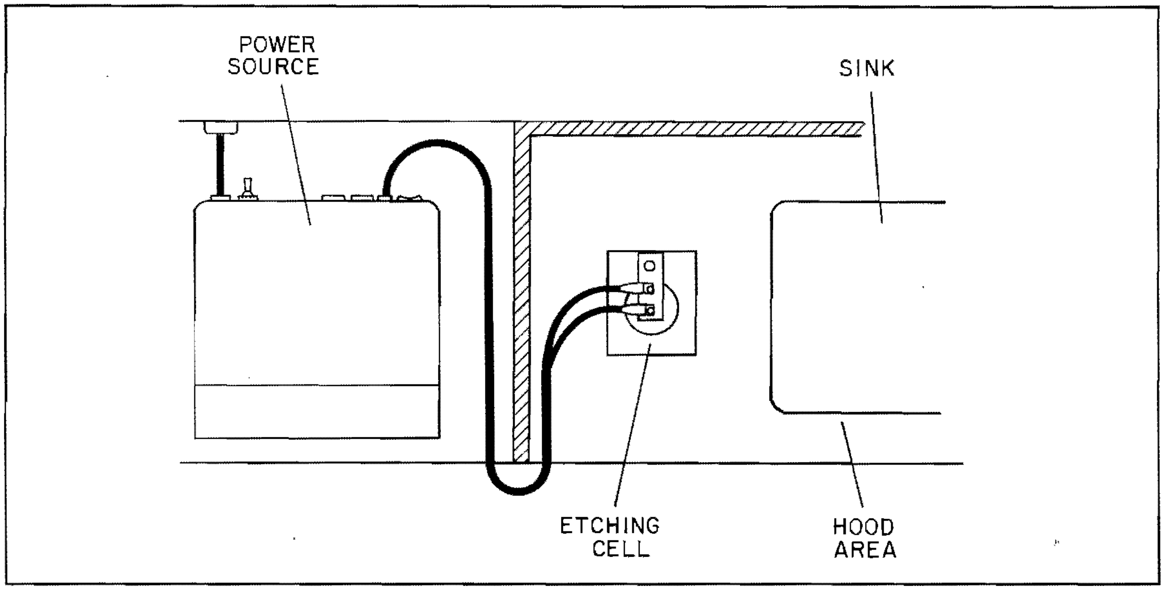


Figure 4. Layout for ELECTROMET® 4 Power Source with Etching Cell (Top View)

To connect the cooling system, insert both hoses into the Plastic Hose Fittings on top of the Polishing Cell (Figure 3). Turn the plastic nuts clockwise to tighten.

CAUTION **Tighten with finger pressure only; do not use a wrench.**

NOTE: 2nd Hose is missing, be sure to secure one

Take either hose and attach the free end to the water supply. Extend the remaining hose to an open drain. Check for leaks and reconnect if required.

Polishing Cell Pre-operational Check (Figure 2)

When all the electrical and plumbing connections have been completed, operation should be checked, using water instead of an electrolyte. Fill the Electrolyte Tank with approximately 1 liter of water. Place the Tank on the Cell Base, allowing the Alignment Pins in the Cell Base to engage the Alignment Holes on the bottom of the Tank. Position the Pump Impeller in the bottom of the Electrolyte Tank. The powerful magnetic drive in the Cell Base will cause the Impeller to self-align.

Put the Pump Body Assembly into the Electrolyte Tank so that the Lower Pump Housing encloses the Impeller. Select the desired mask and position it over the Cathode Tube opening.

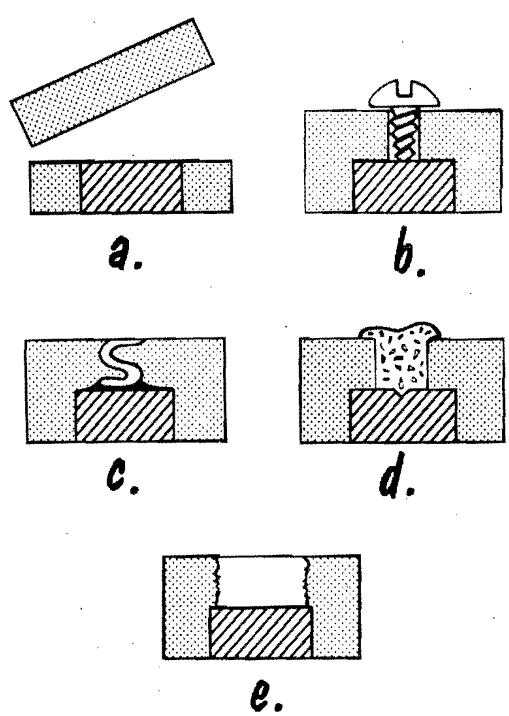
Press the Control On Button and the Pump On Button. Press the Pump Increase Button to increase the Pump speed. The water should rise to the top of the Cathode Tube and flow over the Mask. If the water does not rise, press the Pump Off Button and remove the Pump Body Assembly. Make sure the Impeller is free and return the Pump Body Assembly to the Electrolyte Tank. When normal operation is observed, remove the water from the tank.

Polishing Theory

Electrolytic polishing produces a highly polished distortion-free surface that is ideal for microscopic examination. Because abrasives are not used, there are no deformation layers to obscure the microstructure. Generally, pure metals and simple solid solution alloys such as stainless steel, aluminum, copper and titanium polish well. The more heterogeneous alloys, such as cast irons and most carbon steels, are much less responsive to electrolytic polishing. Electrolytically polished surfaces are also useful for surface sensitive tests where even small amounts of surface deformation are unacceptable.

Electrolytic polishing occurs when micro-elevations (scratches) on the specimen surface are removed by electrolytic dissolution. A surface that is uniformly abraded to a 600 grit or a finer finish is normally an acceptable starting point. The specimen is the anode in the electrolytic cell formed by pumping an electrolyte (selected from Tables 1 and 2) through the cathode tube to the specimen surface. A specified direct current is applied across the specimen for a selected time interval. At the conclusion of the polishing, the specimen is removed, washed and dried. If the correct conditions have been selected, a bright, smooth, highly polished area will be created.

To achieve a complete circuit, electrical contact must be made with the back of the specimen. If the specimen is encapsulated, some special method of obtaining electrical contact may be required. Some suggested techniques are illustrated in Figure 5.



a) Mount is cut so that the back of the specimen is exposed for direct contact with the current.

b) A hole is drilled into the back of the mount so that a stainless screw or pin driven into the hole will contact the specimen.

c) Wire contact is particularly useful for cold mounting and is reliable as long as a wire may be soldered, welded, or otherwise attached to the specimen. By extending the wire to the back surface, it may be attached to a contact block or reset itself as the electrical contact.

d) A hole is drilled into the back of the mount and solder or fusable alloy is cast so that it contacts the back of the specimen. The hole should be large enough to allow the metal to flow easily into the hole.

e) A tube, the approximate ID as the specimen, is placed on the specimen as it sits in the ram face in its down position. A conductive encapsulant is poured into the tube to a height slightly higher than the normal level. Glass-filled diallyl phthalate is then poured around the outside of the tube, filling the remainder of the area. When the tube is withdrawn, there is a column of uncured conducting epoxy in contact with the specimen within an outer non-conducting shell of glass-filled diallyl. The mount is then cured under the recommended heat and pressure, producing a mount that will conduct both heat and electricity.

f) (Not Shown) specimen is mounted in conductive encapsulant.

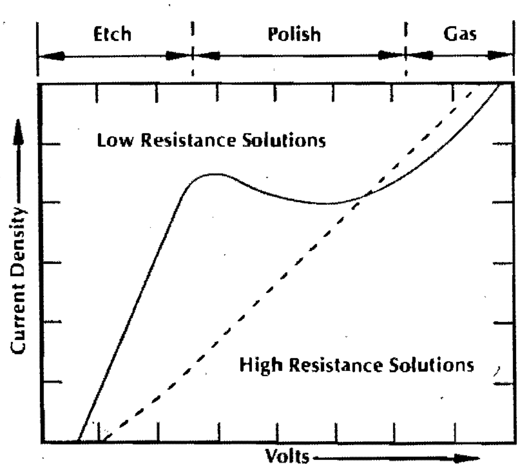
Figure 5. Methods for Making Conductive Mounts

In actual practice, it is usually necessary to make several attempts before the optimum conditions are established. Trial specimens should be run and the results microscopically examined. To correct problem conditions, refer to Table 4 "Trouble Shooting Chart," make the recommended adjustments, and perform new trial polishes until satisfactory results are obtained. Once acceptable conditions are achieved, repetitive results can be expected.

Polishing Parameters

Specific parameters which affect the polishing results and the controls involved are as follows:

1. Electrolyte Composition (Operator Selection)	Depends on the specimen composition and thermal history. (See Tables 1 and 2)
2. Mask Size (Operator Selection)	Select the smallest aperture to provide the surface area required. (See Table 3)
3. Electrolyte Flow Rate (Pump Section of Control Panel)	Must be adequate to cover specimen surface without turbulence.
4. Voltage/Current (Polish/Etch Section of Control Panel)	Adjust to produce current density required to obtain polishing (See Figure 6). Low values produce etching; high values produce gassing and heat.
5. Time (Time Section of Control Panel)	Use the shortest time needed to produce acceptable results. Long times produce relief, pitting and artifacts. Short times produce inadequate polishing and/or scratches.
6. Temperature (Temperature LED Readout—Water Supply)	Follow published recommendations. Keep electrolyte temperature constant to maintain uniform results and avoid unsafe conditions.
7. Specimen Preparation (Operator Technique)	Usually 600 grit is adequate; finer preparation is required in some cases.



To determine the correct conditions for low resistance solutions, increase the voltage slowly from zero. The current will increase uniformly at first. When the current begins to fall even with a continued increase in voltage, the Polishing Plateau has been reached. The best polishing conditions are normally just beyond this point.

Figure 6. Voltage-Current Density Curves

Etching

Etching with the ELECTROMET® 4 unit may be accomplished either in the Polishing or the Etching Cell. Some specimen materials will etch in the same electrolyte used for polishing. In such instances, etching may be done in the Polishing Cell, either concurrently or as an independent operation. For concurrent polishing-etching, set both the polish and etch times as indicated above. When the normal polishing cycle is completed, the etching cycle will begin automatically.

For independent etching in the Polishing Cell, set the Etch Time as indicated above except set the Polish Time to zero and do not press the Polish On Button. Instead press the Etch On Button.

The Etching Cell should be used when an electrolyte other than that used for polishing is desirable. To perform external etching, make the necessary connections described under installation. Make sure the Etch/Polish Selector Switch on the rear panel of the Power Source is depressed toward Etching Cell Socket. Select an appropriate electrolyte from Table 5 and fill the Electrolyte Container about 3/4 full. When etching a mounted specimen, place the specimen on the bottom of the Electrolyte Container, polished side up. Lower the Arm Assembly so that the point of the Anode Rod contacts the specimen, preferably near the center. Adjust the height of the Vertical Cathode, if required, so that it is fully immersed, but not in contact with the specimen. Unmounted specimens should be secured in the Unmounted Specimen Clamp, polished side down. Place the Horizontal Cathode in the electrolyte and lower the Arm Assembly until the polished face of the specimen is barely covered by electrolyte.

Electrolytic etching is similar to electropolishing except that it occurs at a lower voltage (see Figure 6) and does not usually require a continual flow of electrolyte. Etching normally occurs in the 3-5 volt D.C. range, as monitored by Volt LED Display.

The Stainless Steel Cathode is used for most specimens but, in some applications, other materials may be required. Consult Table 5 for recommended cathode materials.

Operation

Polishing Cell (Figure 7)

The Polishing Cell can be used for polishing, etching or a combination of both.

- Fill Electrolyte Tank. All Cooling Coils should be submerged.
- Use acid resistant tongs to position the Impeller in the Tank.
- Place Pump Assembly in the Tank so that the Lower Pump Housing encloses the Impeller.
- Select and position a Mask. **NEVER** OPERATE WITHOUT A MASK.

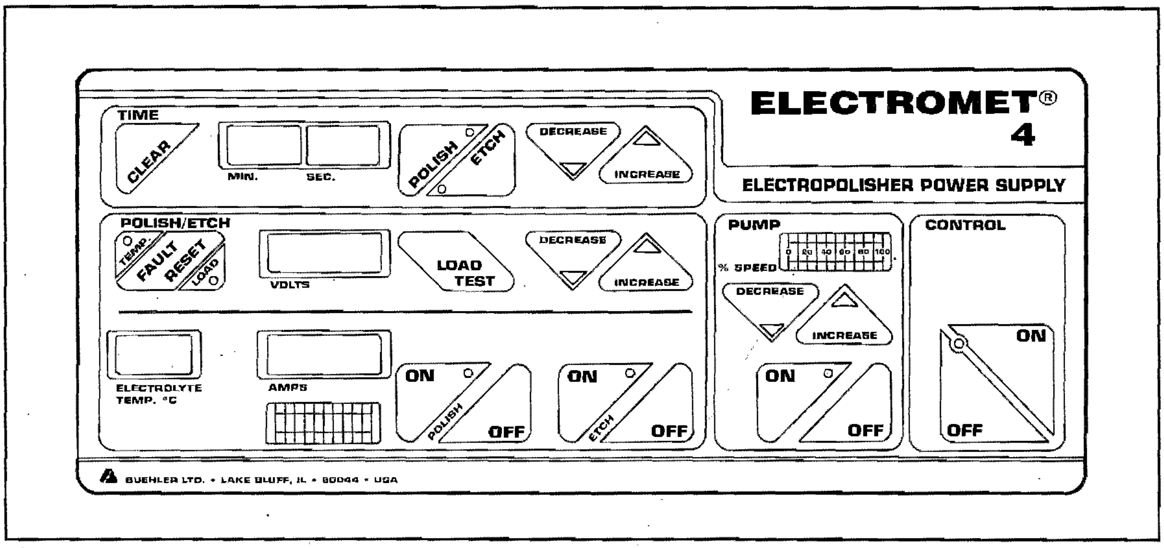


Figure 7. Control Panel

- Press Control On Button. LED will light.
- Press the Pump On Button and adjust the pump speed, using the Pump Increase and Decrease Buttons, so the electrolyte will rise to fill Mask opening and overflow slightly.
- Press the Pump Off Button but do not change the speed setting.
- Place specimen, face down, on Mask.
- Slide Anode Arm down to make electrical contact with back of specimen.
- If Polishing is desired, press Time Polish Button. LED will light. Set Time LED Display for the desired polish time using the Time Increase and Decrease Buttons. The Time Clear Button will reset the polish time to zero.

NOTE If the unit is run for a long period of time without cooling, the Fault Temperature LED will begin to blink at approximately 46° - 51° C, warning the operator to cool the electrolyte. If the operator does not cool the electrolyte, the temperature will generally rise and the Fault Indicator will stay on at 51° - 56° C and the unit will shut down. When the temperature falls below 45° C, the unit can be restarted.

- If Etching is desired, press Time Etch Button. LED will light. Set Time LED Display for the desired etch time using the Time Decrease and Increase Buttons. The Time Clear Button will reset the etch time to zero.

NOTE If Etching is not desired, press the Time Etch Button and clear the etch time pressing the Time Clear Button. If the etch time is not cleared to zero, the unit will automatically go into etch after polishing cycle is completed.

- Set the Volts LED Display to the desired voltage using the Volts Increase and Decrease Buttons.

- Press and hold the Load Test Button. Adjust the Volts Increase and Decrease Buttons until the recommended current density or until voltage/current plateau is reached, as monitored on the AMPS LED Digital Display and Bar Graph. The Bar Graph will detect he current plateau since it is not indicating instantaneous current as is the Digital Display.

NOTE If the unit is run at a current too high for the specimen, the Fault Load LED will light and the unit will shut down. When the load is reduced, press the Fault Reset Button to restart the cycle.

- If polishing was set, press the Polish On Button to start the cycle. The LED will light. When polishing cycle is over, the LED light will extinguish. If Etching was set, the Etch LED will light and the unit will begin the etching cycle.
- If etching only was set, press the Etch On Button to start the cycle. The LED will light. When the etching cycle is over, the LED light will extinguish.

NOTE During the cycle, the Time LED will count down the cycle time to zero.

- During the operating cycle, observe the Electrolyte Temperature LED Readout. This displays the actual temperature of the electrolyte.

  At the end of the cycle, press the Pump Off Button, lift the Anode Arm, and remove the specimen with acid resistant tongs. **NEVER REMOVE SAMPLE WHILE POLISHING OR ETCHING IS IN PROGRESS.**
- Wash specimen thoroughly, dry, and examine.

Etching Cell (Figure 7)

- Determine nominal composition of specimen to be etched.
- Select suitable electrolyte and fill Container 3/4 full.
- Place mounted specimen, face up, on the bottom of container, using tongs. Lower Anode Rod to make contact with specimen surface.
- Lower Unmounted Specimen Clamp until polished specimen face is barely covered by electrolyte.
- Press Time Etch Button. LED will light.
- Set Time LED Display for the desired etch time using the Time Increase and Decrease Buttons. The Time Clear Button will reset the etch time to zero.
- Set the Volts LED Display to the desired voltage using the Volts Increase and Decrease Buttons.
- Press and hold the Load Test Button. Adjust the Volts Increase and Decrease Buttons until the recommended current density or until voltage/current plateau is reached, as monitored on the amps LED Digital Display and Bar Graph.

NOTE If the unit is run at a current too high for the specimen, the Fault Load LED will light and the unit will shut down. When the load is reduced, press the Fault Reset Button to start the cycle over.

- Press the Etch On Button to start the cycle. The LED will light.

NOTE During the cycle, the Time LED will count down the cycle time to zero.

- When etching cycle is over, the LED light will extinguish.
- Raise Arm Assembly, remove specimen with tongs, wash and dry.

Maintenance

After use, mixed electrolytes should be returned to the storage bottle. If the electrolyte is noticeably discolored, it should be discarded according to local guidelines for chemical disposal. Wash the Electrolyte Tank and Pump Assembly thoroughly after each use. Wipe the Cell Base surfaces with a sponge or damp cloth and wipe dry. The Power Source should be wiped off periodically or immediately after having been splashed by electrolytes or component chemicals.

General Specifications

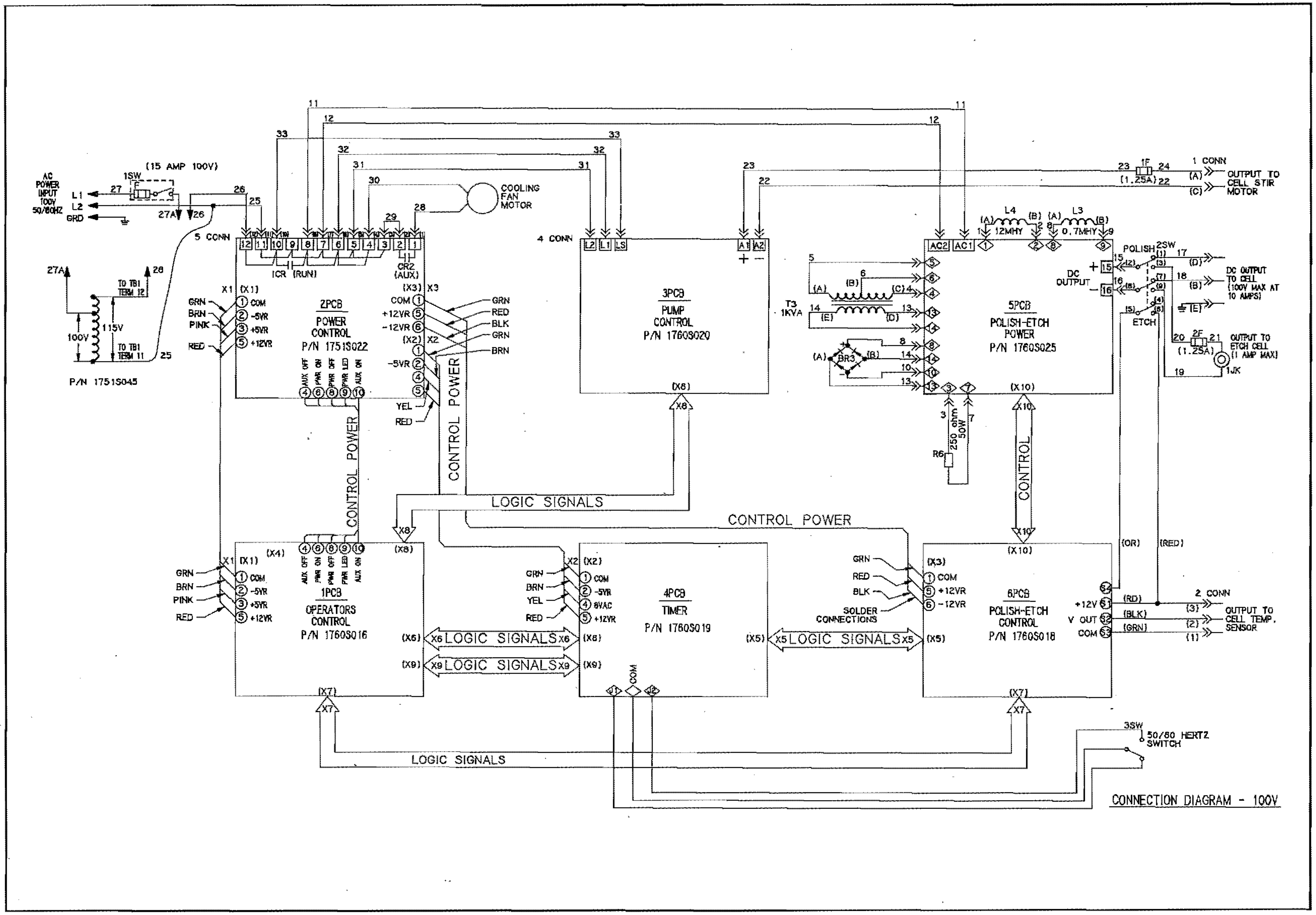
ELECTROMET 4 tested in our laboratory, background noise level 45.6 dBA.

Precautions Regarding the Use of Electrolytes

- Mix all electrolytes with extreme care, using proven formulations and recommended laboratory practice—do not experiment.
- Never pour solvent liquid into concentrated acids, particularly sulfuric acid.
- Never allow re-used electrolytes to become too concentrated due to normal evaporation. Keep loosely covered with pop-off lids. Maintain the original concentration by adding additional solvent liquid if necessary. Concentration is particularly important when using electrolytes containing perchloric or nitric acid.
- Keep all storage bottles identified as to contents and recommended use.
- Dispose of discolored electrolytes according to corporate, or local guidelines for waste chemicals.
- Store electrolytes under proper temperature and safety conditions.

NOTE Maintain the recommended operation temperature for the electrolyte. Elevated temperatures increase the risk of explosion.

Figure 8. ELECTROMET® 4 Connection Diagram (100V)



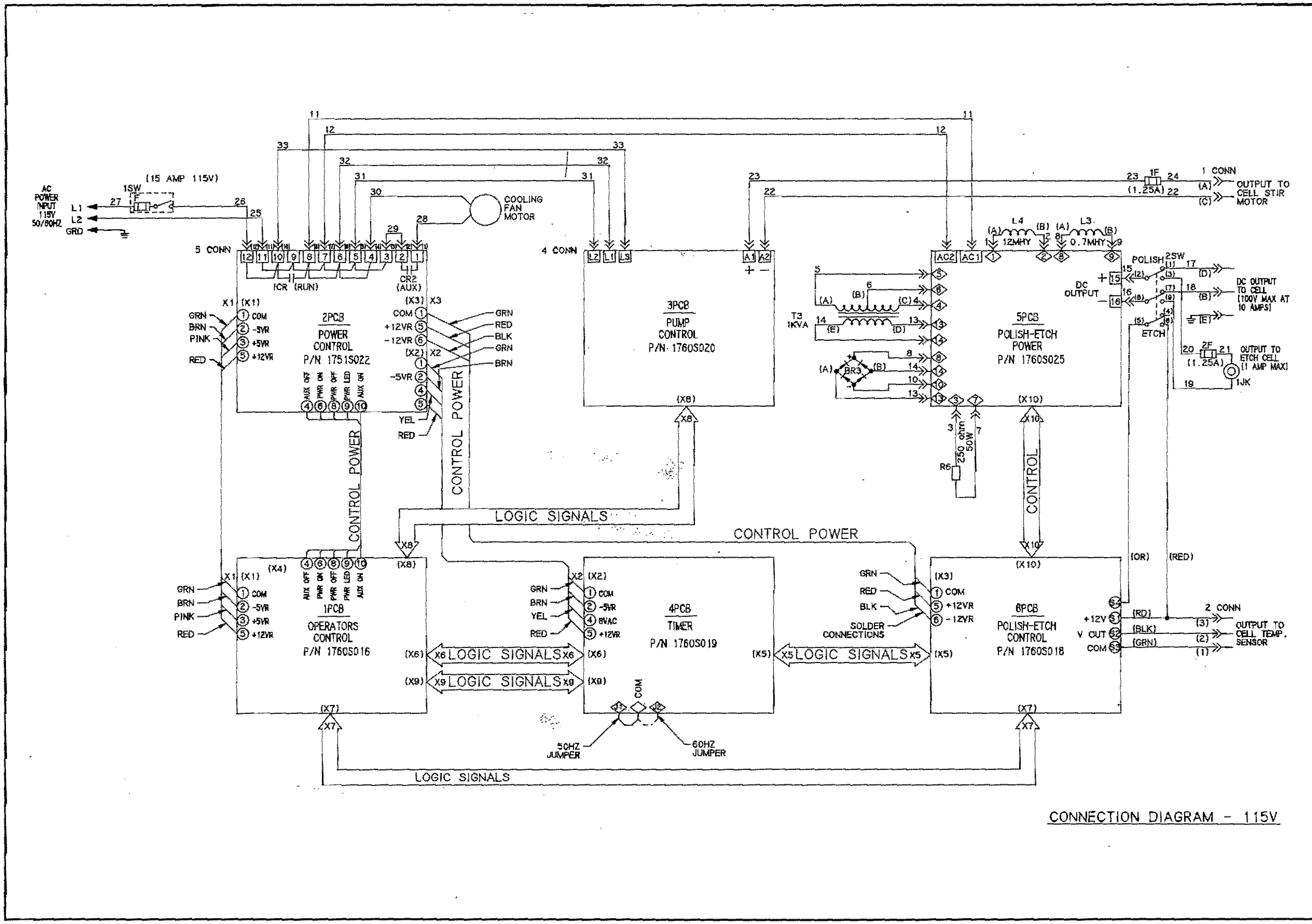
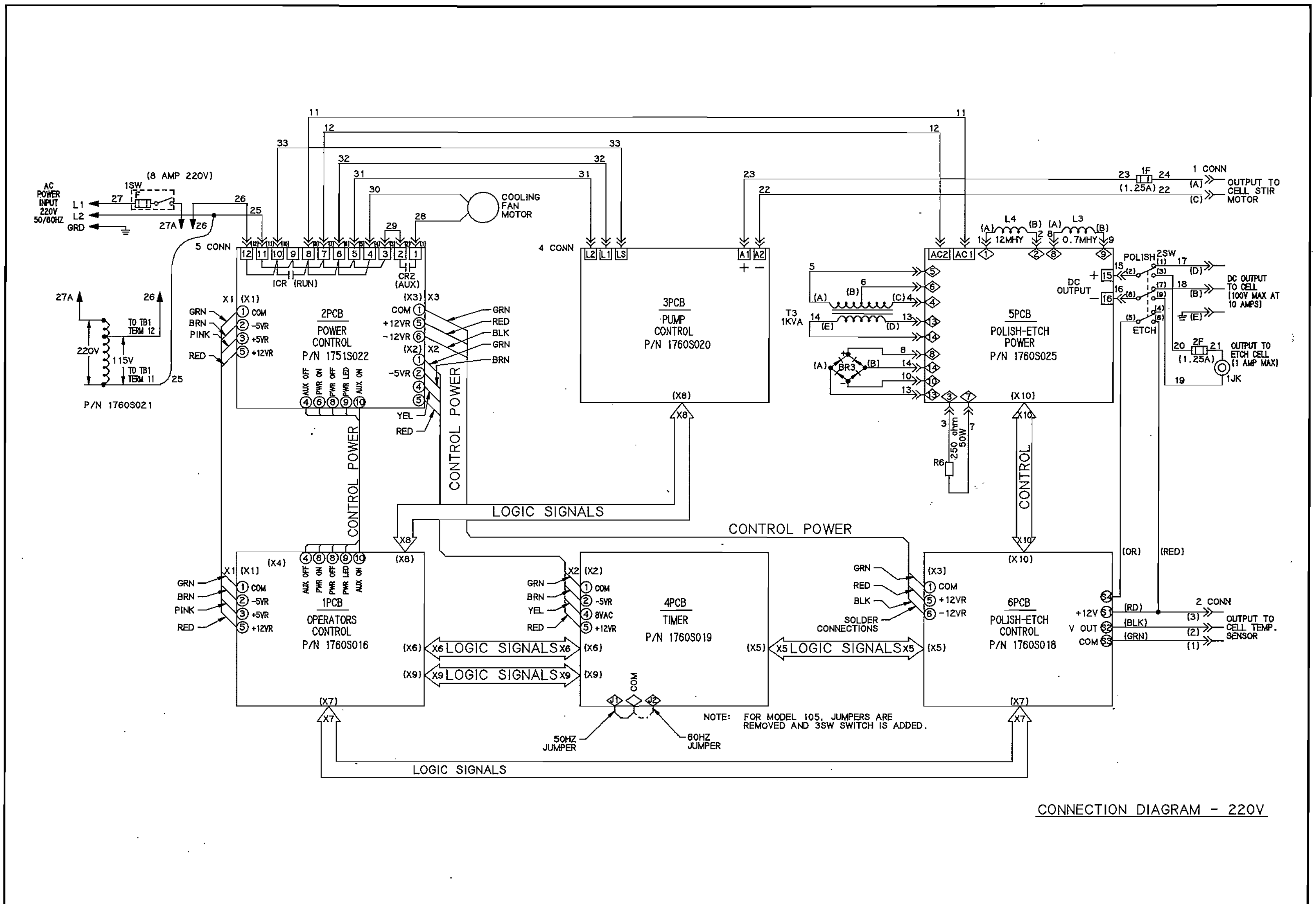


Figure 9. ELECTROMET® 4 Connection Diagram (115V)

Figure 10. ELECTROMET® 4 Connection Diagram (220V)



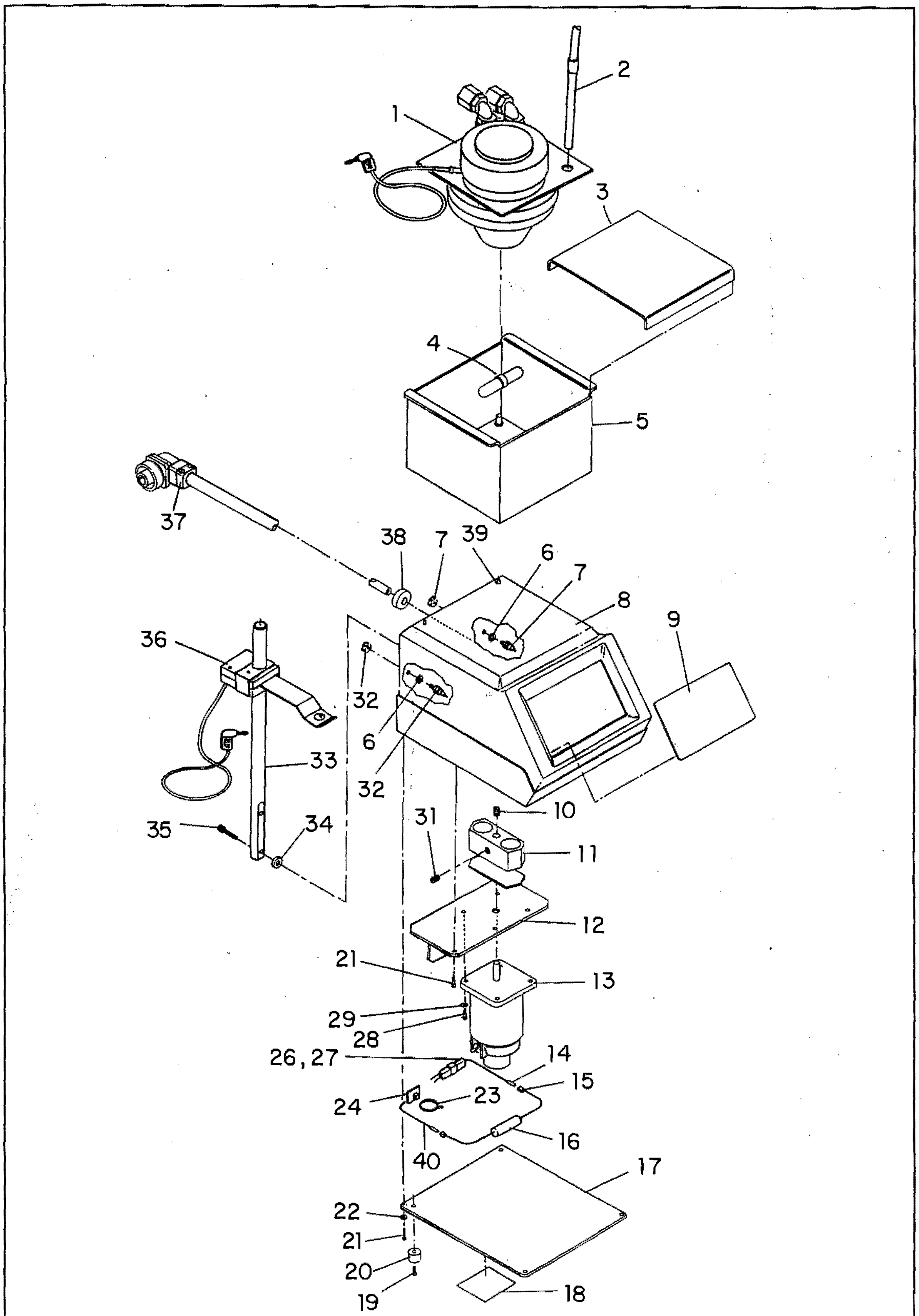


Figure 11. Parts Diagram for ELECTROMET® 4 Polisher/Etcher Polishing Cell

ELECTROMET® 4 Polisher/Etcher Polishing Cell Parts List

REF	PART NO.	QTY	DESCRIPTION
1	1832S022	1	Pump Chamber Assembly
2	1760S026	1	Temperature Probe Assembly
3	1732S021	1	5/32 Inch Hex Wr Cd Pl
4	R-7324	1	Stirring Bar
5	1732S011	1	Tank
6	R-8039	2	Lockwasher 1/4 In External
7	R-7241	1	Jack, Phono Red
8	1832S010	1	Housing - Cell Pump
9	1832S016	1	Nameplate Electromet 4 Cell
10	R-1314	1	Screw Set 5/16-18 5/16 In SS
11	1700S509	1	Magnet Drive Assembly
12	1832S013	1	Plate - Motor Mount
13	1832S011	1	Motor 1/30 HP DC 90V
14	R-8592	2	Terminal .187 Flag Fully Ins
15	R-8456	2	M/F Piggyback Disconnect
16	R-7299	1	Resistor 750 Ohm 20W
17	1832S014	1	Cover - Bottom
18	1832S026	1	Specification Plate
19	R-8732	4	Screw, St. 8-32 X 1/2 Ph Pn Hd SS Pa
20	R-2700	4	Bumper Alt #18 - Mounting Feet
21	R-1663PPH	8	Screw 10-32 1/4 In Cr Pn Hd SS
22	R-0612LW	4	Lock Washer #10 SS
23	R-0585	1	Tie Strap .10 X 4 In
24	R-8370	1	Mount Cable Tie
26	R-7042	2	Molex Pin Male
27	R-7045	1	Molex Plug 2 Connector
28	R-7491	4	Screw 6-32 3/8 In Cr Pan Hd SS
29	R-0605LWE	1	Washer, Lock
31	R-1303	2	Screw Set 1/4-20 1/4 In SS
32	R-7242	1	Jack, Banana Black
33	1832S018	1	Post, Support
34	1832S019	2	Spacer 1/2 X .194 X 1
35	R-8004	2	Screw 10-32 1-3/4 In Skt Hd
36	1732S052	1	Anode Assembly
37	1732S032	1	Umbilical Cord and Plug
38	R-8635	1	Bushing, Cord
39	1832S020	2	Pin - Shoulder 10/32
40	R-0414	12	Wire #16 Black Stranded

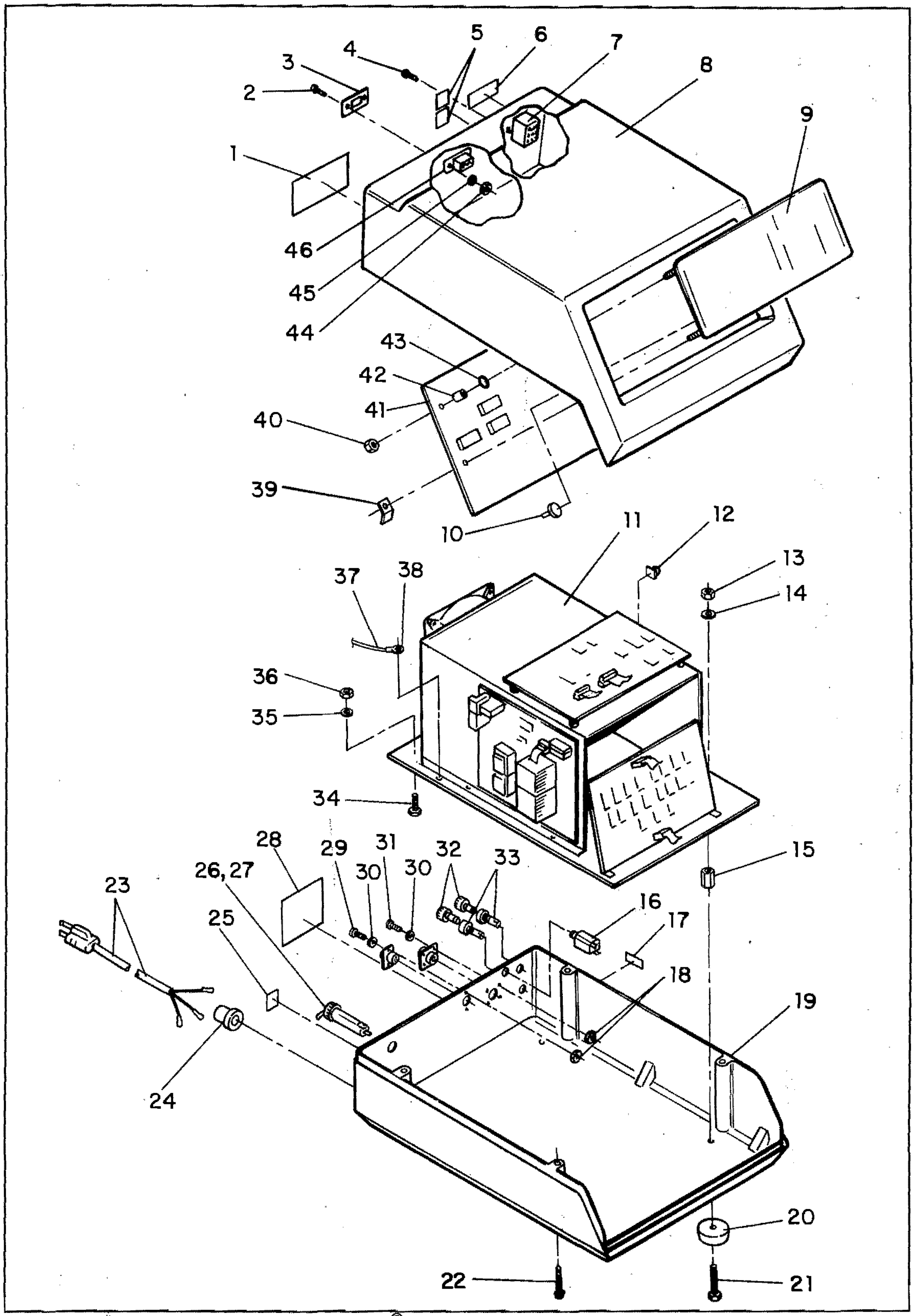


Figure 12. Parts Diagram for ELECTROMET® 4 Polisher/Etcher Power Supply

ELECTROMET® 4 Polisher/Etcher Power Supply Parts List

REF.	PART NO.	QTY.	DESCRIPTION
1	1790S062	1	Bi-Lingual Caution Plate
2	R-8550	2	Screw #2-56 X 1/2 CR Pan Hd SS (100 V)
3	1760S040	1	Switch Plate 50/60 Hz (100 V)
4	R-1625	2	Screw 6-32 3/8 In Slt Rd Hd SS
5	1760S053	2	Fuse Plate MDX 1-1/4
6	1731S010	1	Selector Plate
7	R-7290	1	Switch 4PDT
8	1760S010	1	Cabinet Upper
9	1760S042	1	Nameplate Electromet 4
10	R-8571	19	Button-Switch Control Panel
11	1760S024	1	Power Supply Assembly-Elect. (115 V)
	1760S035	1	Power Supply Assembly Elect. (220 V)
12	R-7482	1	Clip, Component 1/2 Dia.
13	R-0614	4	Nut 1/4-20 Hex
14	R-0615LW	4	Lockwasher 1/4 In SS
15	1832S015	4	Spacer .250 ID X .500 Long
16	R-7281	1	Etch Jack Isolated
17	1760S041	1	Label Elect. Component
18	R-0603	6	Nut 4-40 Hex SS
19	1760S011	1	Cabinet Lower
20	R-7886	4	Bumper, Rubber
21	R-2408	4	Screw 1/4-20 1-3/4 In Hex Hd SS
22	R-8465	4	Screw 10-16 x 1 Hex Hd SS
23	1731S022	1	Power Cord (115 V)
	1270S078	1	Power Cord (220 V)
24	R-4536	1	Bushing-Cord (115 V)
	R-4535	1	Bushing Cord (220 V)
25	1751S039	1	Fuse Plate 15 MDA (115 V)
	1760S054	1	Fuse Plate MDA 8 (220 V)
26	R-7409	2	Fuse 15 Amp (115 V)
	R-4554	2	Fuse 8 Amp (220 V)
27	R-8347	1	Fused Switch 20/15/A 120/250V
28	1760S056	1	Specification Plate (100 V) CE
	1760S057	1	Specification Plate (115 V) CE
	1760S058	1	Specification Plate (220 V) CE
29	R-8321	2	Screw 4-40 5/8 In. Cr Flat Hd
30	R-0603LW	6	Lockwasher #4 Stainless Steel
31	R-8086	4	Screw 4-40 1/2 In Cr Pan Hd SS
32	R-7705	3	Fuse 1.25 A 250V
33	1305S17	2	Fuse Post
34	R-8078	1	Screw 10-32 7/8 In Cr Pan Hd SS
35	R-0612LWE	3	Lock Washer #10 Ext SS
36	R-0612	3	Locknut 10-32 Hex SS
37	1702S017	1	Wire Ground 40 In
38	R-0539	1	Terminal #10 Ring 16-14 NIT
39	R-8544	1	Connector, Male Tab .187
40	1180S72	8	Nut 16-32 KEPS
41	1760S016	1	PCB Operators Control Panel
42	R-8572	8	Spacer 6-32 .25 Dia. x .420 Long
43	R-8166	4	Retaining Ring Ext .250
44	1180S90	2	Nut 2-56 Hex (100 V)
45	1180S89	2	Lockwasher #2 (100 V)
46	R-8546	1	Switch DPDT Slide (100 V)
	1751S045	1	Transformer 100V - 125V 10 Amp (100 V)*
	5500S044	3	Pin-Connector (100 V)*
	R-16666PPH	4	Screw 10-32 1/2 In CR Pan Hd SS (100 V)*
	R-8458	1	Connector 3 Pin Mole (100 V)*
	R-7693	24	Wire #22 Stranded Black (100 V)*
	R-7692	24	Wire #22 Stranded White (100 V)*
	R-7691	24	Wire 22 Ga Stranded White (100 V)*

* Not Shown

Table 1. Suggested Electrolytes for Metals and Generally Their Alloys*

Metal or Alloy	Electrolyte No.
Aluminum	I-1, I-2, I-4, I-5, I-6, I-8, I-10 II-3, III-7, IV-6
Aluminum-silicon alloys	I-6, I-8
Antimony	II-4
Beryllium	1-4
Bismuth	VI-18, VI-25
Cadmium	III-4
Cast iron	I-4, II-1
Chromium	II-1, VIII-1
Cobalt	I-5, II-3, III-1, III-4, VIII-1
Copper	III-2, III-3, III-4, III-5, III-10, VIII-1
Copper-zinc alloys	III-3, III-4, III-5, III-10, V-2 VIII-1
Copper-tin alloys	III-10, VI-5, VI-6, VIII-1
Copper-nickel alloys	III-3, III-10, VIII-1
Germanium	I-9
Gold	VII-1
Hafnium	VII-11
Iron, pure	I-5, II-1, IV-2, IV-3
Iron-silicon alloys	I-5, I-6, I-8, II-5
Iron-copper alloys	III-3, III-4
Iron-nickel alloys	I-5, II-1, II-2, II-4, IV-3, VIII-1
Lead	I-1, I-5, II-4, VII-5
Magnesium	I-1, III-7, III-12, VI-19
Manganese	III-9
Molybdenum	I-7, IV-4, IV-7, VI-20
Nickel–chromium	II-4, VIII-1
Nickel	I-4, II-4, IV-2, VIII-1
Silicon	VII-5
Silver	III-7, VII-2, VII-3, VII-1
Steel, austenitic, stainless, and super alloys	I-1, I-2, I-3, I-4, I-5, II-1, II-2, II-3, III-3, III-6, III-11, IV-1, IV-2, IV-3, IV-5, IV-6, V-1, VI-1, VI-2, VI-3, VI-4, VI-7, VI-8, VI-9, VI-10 VI-11, VI-13, VI-15, VI-16, VI-17, VIII-1
Steel, carbon and alloy	I-1, I-2, I-4, I-5, II-1, II-2, II-3, II-5, III-6, VI-3, VI-11
Tantalum	VI-12
Tin	I-4, VI-5, VI-6, VII-6
Titanium	I-4, I-9, II-1, II-2, II-3
Tungsten	VII-4, VII-5
Uranium	I-4, I-7, II-1, II-2, II-3, III-8, III-13
Vanadium	I-9
Zinc	I-1, I-5, III-12, V-2, VI-14, VI-23, VII-6, VIII-1
Zirconium	I-4, 1-7, 1-9, II-2, VI-24

Table 2. Electrolytes for Electropolishing*

Class	Use	Formula		Cell Voltage	Time	Remarks
	Group I (electrolytes Composed of Perchloric Acid and Alcohol With or Without Organic Additions)					
I-1	Al and Al alloys with less than 2 percent Si	ethanol (95 percent) distilled water perchloric acid (60 percent)	800 ml 140 ml 60 ml	30 to 80	15 to 60 s	
	steels—carbon, alloy, stainless			35 to 65	15 to 60 s	
	Pb, Pb-Sn, Pb-Sn-Cd, Pb-Sn-Sb			12 to 35	15 to 60 s	
	Zn, Zn-Sn-Fe, Zn-Al-Cu			20 to 60		
	Mg and high Mg alloys					nickel cathode
I-2	stainless steel and aluminum	ethanol (95 percent) perchloric acid (60 percent)	800 ml 200 ml	35 to 80	15 to 60 s	
I-3	stainless steel	ethanol (95 percent) perchloric acid (65 percent)	940 ml 60 ml	30 to 45	15 to 60 s	
I-4	steel, cast iron, Al, Al alloys, Ni, Sn, Ag, Be, Ti, Zr, U, heat-resisting alloys	ethanol (95 percent) 2-butoxy ethanol perchloric acid (30 percent)	700 ml 100 ml 200 ml	30 to 65	15 to 60 s	one of the best formulas for universal use
I-5	steels—stainless, alloy, high-speed; Fe, Al, Zr, Pb	ethanol (95 percent) glycerin perchloric acid (30 percent)	700 ml 100 ml 200 ml	15 to 50	15 to 60 s	universal electrolyte comparable to I-4
I-6	Al, Al-Si alloys	ethanol (95 percent) diethyl ether perchloric acid (30 percent)	760 ml 190 ml 50 ml	35 to 60	15 to 60 s	particulary good with Al-Si alloys
I-7	Mo, Ti, Zr, U-Zr alloy	methanol (absolute) 2-butoxy ethanol perchloric acid (60 percent)	600 ml 370 ml 30 ml	60 to 150	5 to 30 s	
I-8	Al-Si alloys	methanol (absolute) glycerin perchloric acid (65 percent)	840 ml 125 ml 35 ml	50 to 100	5 to 60 s	
I-9	vanadium	methanol (absolute) 2-butoxy ethanol perchloric acid (65 percent)	590 ml 350 ml 60 ml	30	3 s	three-second cycles repeated at least seven times to prevent heating
	germanium			25 to 35	30 to 60 s	
	titanium			58 to 66	45 s	polish only
	zirconium			70 to 75	15 s	polish and etch simultaneously
I-10	aluminum	methanol (absolute) nitric acid perchloric acid (60 percent)	950 ml 15 ml 50 ml	30 to 60	15 to 60 s	

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Table 2. Electrolytes for Electropolishing (Continued)

Class	Use	Formula		Cell Voltage	Time	Remarks
Group II (Electrolytes Composed of Perchloric Acid and Glacial Acetic Acid in Varying Proportions)						
II-1	Cr, Ti, Zr, U Fe, steel carbon, alloy, stainless	acetic acid (glacial) perchloric acid (60 percent)	940 ml 60 ml	20 to 60	1 to 5 min	good general–purpose electrolyte
II-2	Zr,Ti, U, steel—carbon and alloy	acetic acid (glacial) perchloric acid (60 percent)	900 ml 100 ml	12 to 70	0.5 to 2 min	
II-3	U, Zr, Ti, Al, steel—carbon and alloy	acetic acid (glacial) perchloric acid (60 percent)	800 ml 200 ml	40 to 100	1 to 15 min	
II-4	Ni, Pb, Pb-Sb alloys	acetic acid (glacial) perchloric acid (60 percent)	700 ml 300 ml	40 to 100	1 to 5 min	
II-5	3 percent Si-Fe	acetic acid (glacial) perchloric acid (60 percent)	650 ml 350 ml	...	5 min	0.06 A/cm^2
Group III (Electrolytes composed of Phosphoric Acid in Water or Organic Solvent)						
III-1	cobalt	phosphoric acid (85 percent)	1000 ml	1.2	3 to 5 min	
III-2	pure copper	distilled water phosphoric acid (85 percent)	175 ml 825 ml	1.0 to 1.6	10 to 40 min	copper cathode
III-3	stainless, brass, Cu and Cu alloys except Sn bronze	water phosphoric acid (85 percent)	300 ml 700 ml	1.5 to 1.8	5 to 15 min	copper cathode
III-4	alpha or alpha plus beta brass, Cu-Fe, Cu-Co, Co, Cd	water phosphoric acid (85 percent)	600 ml 400 ml	1 to 2	1 to 15 min	copper or stainless steel cathode
III-5	Cu, Cu-Zn	water pyrophosphoric acid	1000 ml 580 g	1 to 2	10 min	copper cathode
III-6	steel	diethylene glycol monoethyl ether phosphoric acid (85 percent)	500 ml 500 ml	5 to 20	5 to 15 min	120 F
III-7	Al, Ag, Mg	water ethanol (95 percent) phosphoric acid (85 percent)	200 ml 380 ml 400 ml	25 to 30	4 to 6 min	aluminum cathode, 100 to 110 F
III-8	uranium	ethanol (absolute) glycerin (cp) phosphoric acid (85 percent)	300 ml 300 ml 300 ml	....	...	
III-9	Mn, Mn-Cu alloys	ethanol (95 percent) glycerin phosphoric acid (85 percent)	500 ml 250 ml 250 ml	18		
III-10	Cu and Cu-base alloys	distilled water ethanol (95 percent) phosphoric acid (85 percent)	500 ml 250 ml 250 ml	...	1 to 5 min	
III-11	stainless steel	ethanol (absolute), to pyrophosphoric acid	1 liter 400 g	...	10 min	good for all austenitic heat resistant alloys, 100 F plus
III-12	Mg-Zn	ethanol (95 percent) phosphoric acid (85 percent)	625 ml 375 ml	1.5 to 2.5	3 to 30 min	
III-13	uranium	ethanol (95 percent) ethylene glycol phosphoric acid (85 percent)	445 ml 275 ml 275 ml	18 to 20	5 to 15 min	0.03 A/cm^2
Group IV (Electrolytes Composed of Sulfuric Acid in Water or Organic Solvent)						
IV-1	stainless steel	water sulfuric acid	250 ml 750 ml	1.5 to 6	1 to 2 min	
IV-2	stainless steel, Fe, Ni	water sulfuric acid	400 ml 600 ml	1.5 to 6	2 to 6 min	
IV-3	stainless steel, Fe, Ni, Mo	water sulfuric acid	750 ml 250 ml	1.5 to 6	2 to 10 min Mo–0.3 to 1 min	particularly good for sintered Mo. Mo—32 to 80 F
IV-4	molybdenum	water sulfuric acid	900 ml 100 ml	1.5 to 6	0.3 to 2 min	particularly good for sintered Mo. 32 to 80 F
IV-5	stainless steel	water glycerin sulfuric acid	70 ml 200 ml 720 ml	1.5 to 6	0.5 to 5 min	
IV-6	stainless steel, aluminum	water glycerin sulfuric acid	220 ml 200 ml 580 ml	1.5 to 12	1 to 20 min	
IV-7	molybdenum	methanol (absolute) sulfuric acid	875 ml 125 ml	6 to 18	0.5 to 1.5 min	32 to 80 F
Group V (Electrolytes Composed of Chromic Acid in Water)						
V-1	stainless steel	water chromic acid	830 ml 620 g	1.5 to 9	2 to 10 min	
V-2	Zn, brass	water chromic acid	830 ml 170 g	1.5 to 12	10 to 60 s	

Table 2. Electrolytes for Electropolishing (Continued)

Class	Use	Formula		Cell Voltage	Time	Remarks
		Group VI (Mixed Acids or Salts in Water or Organic Solution)				
VI-1	stainless steel	phosphoric acid (85 percent) sulfuric acid	600 ml 400 ml	...	...	
VI-2	stainless steel	water phosphoric acid (85 percent) sulfuric acid	150 ml 300 ml 550 ml	...	2 min	0.3 A/cm^2
VI-3	stainless and alloy steel	water phosphoric acid (85 percent) sulfuric acid	240 ml 420 ml 340 ml	...	2 to 10 min	0.1 to 0.2 A/cm^2
VI-4	stainless steel	water phosphoric acid (85 percent) sulfuric acid	330 ml 550 ml 120 ml	...	1 min	0.05 A/cm^2
VI-5	bronze (to 9 percent Sn)	water phosphoric acid (85 percent) sulfuric acid	450 ml 390 ml 160 ml	...	1 to 5 min	0.1 A/cm^2
VI-6	bronze (to 6 percent Sn)	water phosphoric acid (85 percent) sufuric acid	330 ml 580 ml 90 ml	...	1 to 5 min	0.1 A/cm^2
VI-7	steel	water glycerin phosphoric acid (85 percent) sulfuric acid	140 ml 100 ml 430 ml 330 ml	...	1 to 5 min	1 to 5 A/cm^2, 100 F plus
VI-8	stainless steel	water glycerin phosphoric acid (85 percent) sulfuric acid	200 ml 590 ml 100 ml 110 ml	...	5 min	1 A/cm^2, 80 to 120 F
VI-9	stainless steel	water chromic acid phosphoric acid (85 percent) sulfuric acid	260 ml 175 g 175 ml 580 ml	...	30 min	0.6 A/cm^2, 80 to 120 F
VI-10	stainless steel	water chromic acid phosphoric acid (85 percent) sulfuric acid	175 ml 105 g 460 ml 390 ml	...	60 min	0.5 A/cm^2, 80 to 120 F
VI-11	stainless and alloy steel	water chromic acid phosphoric acid (85 percent) sulfuric acid	240 ml 80 g 650 ml 130 ml	...	5 to 60 min	0.5 to A/cm^2, 100 to 130 F
VI-12	tantalum	hydrofluoric acid sulfuric acid	100 ml 900 ml	...	9 min	Graphite cathode, 0.1 A/cm^2, 90 to 100 F
VI-13	stainless steel	water hydrofluoric acid sulfuric acid	210 ml 180 ml 610 ml	...	5 min	0.5 A/cm^2, 70 to 120 F
VI-14	zinc	water chromic acid sulfuric acid sodium dichromate acetic acid (glacial)	800 ml 100 g 46 ml 310 g 96 ml	...		0.002 A/cm^2, 70 to 100 F
VI-15	stainless steel	hydrogen peroxide (30 percent) (Caution) hydrofluoric acid sulfuric acid	260 ml 240 ml 500 ml	...	5 min	0.5 A/cm^2 (Caution) Dangerous
VI-16	stainless steel	water hydrofluoric acid sulfuric acid	520 ml 80 ml 400 ml	...	1 to 4 min	0.08 to 0.3 A/cm^2
VI-17	stainless steel	water chromic acid nitric acid hydrochloric acid sulfuric acid	600 ml 180 g 60 ml 3 ml 240 ml	...		
VI-18	bismuth	glycerin acetic acid (glacial) nitric acid	750 ml 125 ml 125 ml	12	1 to 5 min	0.5 ±A/cm^2 (Caution) This mixture will decompose vigorously after a short time. Do not try to keep.
VI-19	magnesium	ethylene glycol monoethyl ether hydrochloric acid	900 ml 100 ml	50 to 60	10 to 30 s	Bath should be stirred. Cool cracked ice below 35 F
VI-20	molybdemun, sintered and cast	methanol (absolute) hydrochloric acid sulfuric acid	685 ml 225 ml 90 ml	19 to 35	20 to 35 s	Mix slowly. Heat is developed. Avoid contamination with water Below 35 F
VI-21	titanium	ethanol (95 percent) n-butyl alcohol aluminum chloride (anhydrous) (add very slowly) (Caution) zinc chloride (anhydrous)	900 ml 100 ml 60 g 250 g	30 to 60	1 to 6 min	(Caution) Anhydrous aluminum chloride is extremely dangerous to handle

Table 2. Electrolytes for Electropolishing (Continued)

Class	Use	Formula		Cell Voltage	Time	Remarks
		Group VI (Mixed Acids or Salts in Water or Organic Solution)				
VI-22	uranium	acetic acid (glacial) distilled water chromic acid	750 ml 210 ml 180 g	80	5 to 30 min	The chromic acid is dissolved in the water before adding to the acetic acid. Below 35 F
VI-23	pure zinc	ethanol (95 percent) aluminum chloride (anhydrous) **(Caution)** zinc chloride (anhydrous) distilled water n-butyl alcohol	720 ml 50 g 225 g 160 ml 80 ml	25 to 40	0.5 to 3 min	**(Caution)** Anhydrous aluminum chloride is extremely dangerous to handle. Below 60 F
VI-24	zirconium. Polish and etch simultaneously	glycerin **(Caution)** hydrofluoric acid nitric acid	870 ml 43 ml 87 ml	9 to 12	1 to 10 min	**(Caution)** will decompose on standing, dangerous if kept too long
VI-25	bismuth	saturated solution K1 in distilled water hydrochloric acid	980 ml 20 ml	7	30 s	polish 30 s but allow to remain in electrolyte until brown film is dissolved
		Group VII (Alkaline Electrolytes)				
VII-1	gold	water to potassium cyanide potassium carbonate gold chloride	1000 ml 80 g 40 g 50 g	7.5	2 to 4 min	graphite cathode
VII-2	silver	water to sodium cyanide potassium ferrocyanide	1000 ml 100 g 100 g	2.5	To 1 min	graphite cathode
VII-3	silver	water to potassium cyanide silver cyanide potassium dichromate	1000 ml 400 g 280 g 280 g	...	T0 9 min	graphite cathode, 0.003 to 0.009 A/cm^2
VII-4	tungsten	water to trisodium phosphate	1000 ml 160 g	...	10 min	graphite cathode, 0.09 A/cm^2, 100 to 120 F
VII-5	tungsten, lead	water to sodium hydroxide	1000 ml 100 g	...	8 to 10 min	graphite cathode, 0.03 to 0.06 A/cm^2
VII-6	zinc,tin	water to potassium hydroxide	1000 ml 200 g	2 to 6	15 min	acopper cathode, 0.1 to 0.2 A/cm^2
		Group VIII (Mixture of Methyl Alcohol and Nitric Acid)				
VIII-1	Ni, Cu, Zn, Monel, brass, Nichrome, stainless steel	methanol (absolute) nitric acid	660ml 330 ml	40 to 70	10 to 60 s	very widely useful but dangerous

Table 3. Mask Sizes and Orifice Areas

Mask	Orifice Dia.	Area
A	0.36" 0.91 cm	0.10 in^2 0.65 cm^2
B	0.50" 1.27 cm	0.20 in^2 1.27 cm^2
C	0.71" 1.80 cm	0.40 in^2 2.54 cm^2
D	0.87" 2.21 cm	0.59 in^2 3.84 cm^2
E	0.59"* 1.50 cm	0.35 in^2 2.25 cm^2

*Square orifice

Table 4. Troubleshooting Chart

Problem	Possible Cause	Suggested Remedy
Center of Specimen Deeply Etched	No Polishing Film at Center of Specimen	Increase Voltage Decrease Agitation Use more Viscous Electrolyte
Pitting or Etching at Edges of Specimen	Too Viscous or Thick Film	Decrease Voltage Increase Agitation Use Less Viscous Electrolyte
Sludge on Surface	Insoluble Anode Product	Try New Electrolyte Increase Temperature Increase Voltage
Roughness or Matte Surface	Insufficient or No Polishing Film	Increase Voltage Use More Viscous Electrolyte
Waviness or Streaks on Polished Surface	Insufficient Time Incorrect Agitation Inadequate Prepreparation Too Much Time	Increase or Decrease Agitation Better Prepreparation Increase Voltage and Decrease Time
Stains on Polished Surface	Attack After Polishing Current is Off	Try Less Corrosive Electrolyte
Unpolished Spots (Bullseyes)	Gas Bubbles	Increase Agitation Decrease Voltage Tilt Specimen
Phases in Relief	Insufficient Polishing Film	Increase Voltage Better Prepreparation Decrease Time
Pitting	Too Long Polishing Too High Voltage	Better Prepreparation Decrease Voltage Decrease Time Try Different Electrolyte

Table 5. Recommendations for Electrolytic Etching

Metal	Bath Composition	Temperature °C	°F	Electrical Conditions	Cathode Material	Time	Remarks
Aluminum	210 parts orthophosphoric acid 45 parts amyl alcohol 65 parts distilled water	24	75	0.75 to 1.2 amp/sq cm	Stainless steel	1.5 to 2.5 min	For 2S & 3S Al.
Brass	3 parts orthophosphoric acid 5 parts water	16 to 27	60 to 80	0.01 amp/sq cm	Copper	Few seconds	Alpha and beta brass
Brass	4 parts orthophosphoric acid 6 parts water	24	75	0.008 to 0.012 amp/sq cm	Copper	Few seconds.	Alpha brass.
Bronze	67 parts orthophospohric acid 10 parts sulfuric acid (conc) 23 parts distilled water	24	75	0.8 volt	Copper	30 sec	For bronze containing up to 6% Sn.
Bronze	47 parts orthophosphoric acid 20 parts sulfuric acid (conc) 33 parts distilled water	24	75	0.8 volt	Copper	30 sec	For bronze containing more than 6% Sn.
Cobalt	Orthophosphoric acid	24	75	1.2 volts	Stainless steel	Few seconds	Agitate bath.
Cobalt and Alloys	5 parts hydrochloric acid 1 to 10 parts chromic acid (10%)	24	75	6 volts	Platinum or stainless steel	10 sec	Cathode distance, 3/4 to 1 in.
Copper	2 parts orthophosphoric acid 1 part distilled water	24	75	0.8 volt	Copper	30 sec	Suitable for alloys except tin bronzes.
Germanium	Oxalic acid (100g/1 water)	24	75	4 to 6 volts	Stainless steel	10 to 20 sec	Grain boundary etch.
Molybdenum	Oxalic acid (0.5%)	52	125	3 to 9 volts	Stainless steel	5 sec	
Molybdenum	Sodium hydroxide (10%)	24	75	1.5 to 3 volts	Platinum or stainless steel	1 to 5 sec	
Nickel and Alloys	Chromic acid (10%)	24	75	1.5 volts	Platinum or stainless steel	1 to 3 sec	
Nickel and Alloys	2 parts nitric acid (conc) 1 part glacial acetic acid 17 parts water	24	75	1.5 volts	Stainless steel	20 to 60 sec	Good for nickel alloys. Excellent for grain size.
Nickel and Alloys	Oxalic acid (10%)	24	75	1.5 to 6 volts	Platinum	15 to 30 sec	Good for Inconel.
Nickel and Alloys	Sulfuric acid (3%)	24	75	6 volts	Stainless steel	5 to 30 sec	Shows carbides and grain boundaries. Inconel and nickel-chromium alloys.
Silver Alloys	Citric acid (10%) plus few drops nitric acid	24	75	6 volts 0.01 amp/sq cm	Stainless steel	15 sec	General use.
Steel	2 g picric acid 25 g sodium hydroxide 100 ml distilled water	24	75	6 volts	Stainless steel	30 sec	Low-alloy steel. Stains iron carbides.
Steel	Chromic acid (10%)	24	75	3 volts	Stainless steel	Variable	Austenitic or ferritic stainless. Attacks carbides and sigma.
Steel	Oxalic acid (10%)	24	75	3 volts	Stainless steel	Variable	
Steel	1 part nitric acid 1 part glycerine 3 parts hydrochloric acid	24	75	3 to 6 volts	Stainless steel or carbom	10 sec	Stainless (16-25-6) Etches austenite.
Steel	1 part nitric acid 1 part water	24	75	1.5 volts	Stainless steel	Up to 2 min	Austenitic or ferritec stainless. Etches grain boundries.
Steel	1 part sulfuric acid 19 parts water	24	75	6 volts 0.1 to 0.5 amp	Stainless steel	5 to 15 sec	For Fe-Cr-Ni alloys.
Steel	Ammonium persulfate (10 to 100 g/1 water)	24	75	6 volts 0.1 to 0.5 amp	Stainless steel		Attacks carbide, ferrite and austenite in that order.
Steel	Sodium hydroxide (400 g/1 water)	24	75	1.5 to 2 volts	Stainless steel		Colors sigma and carbides but not ferrite.
Tantalum	Sodium hydroxide (10 g/1 water)	24	75	6 volts	Stainless steel	3 to 10 sec	General etch.
Tungsten	Sodium hydoxide (10%)	24	75	1.5 to 3 volts	Platinum or stainless steel	1 to 5 sec	For tungsten and tungsten carbides.
Uranium	4 parts citric acid 1 part nitric acid 195 parts water	24	75	0.01 amp/sq cm	Stainless steel	10 min	Outlines grain boundaries
Vanadium	1 part hydrochloric acid 9 parts water	24	75	3 to 6 volts	Stainless steel	Few seconds	