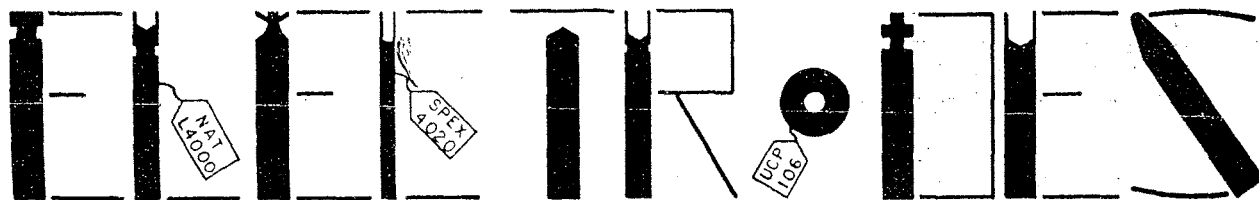


THE SPEX SPEAKER

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Looking me squarely in the eye, a thoroughly bewildered neophyte spectrographer recently complained, "It's high time someone set us right on the odd facts about graphite electrodes. Hundreds of preforms to choose from, differences in density, grade, type, purity, what shall I use anyhow?"

"All right, I've been volunteered," was my painful reply..

Advantages of Graphite

Why is graphite the material chosen for at least 95% of all spectrographic electrodes? Because it has a neat package of useful properties. Among these are the following:

- 1) It is available in high-purity form at a reasonable cost.
- 2) It is easily machinable.
- 3) It has fair electrical and thermal conductivity.
- 4) It does not absorb appreciable moisture.
- 5) It provides a chemically reducing atmosphere to an arc discharge.
- 6) It is non-toxic.
- 7) It emits few spectral lines or bands.
- 8) It produces an arc with a high ionization potential.
- 9) It may be porosified simply by heating.

Some of the above points merit further consideration. Points 3 and 8 are responsible for the high sensitivity attributed to the carbon or graphite arc. Material with higher conductivity, such as copper, conducts heat away so rapidly that the material to be analyzed remains relatively cool. In addition, the shower of copper ions in the arc stream reduces the excitation potential of the arc. The reverse of both these characteristics is true for graphite so that the sensitivity of many elements is better in a graphite arc than most other materials.

Point 4 permits graphite to be used as a buffer as well as an electrode. By contrast, a material which does absorb moisture sputters ominously in an arc. Graphite powder is usually mixed with a sample to be analyzed because it provides a reducing atmosphere (5) and so inhibits the formation of refractory beads. When formed, such beads are non-conductive and dance teasingly in an electrode cup before their suicide jump to the floor.

Although graphite is non-toxic (point 6), upon being arced it does form cyanogen, a poisonous gas. This, however, immediately burns to liberate carbon dioxide and nitrogen. Cyanogen

gives rise to bands which mask out a few short spectral regions. Otherwise, as stated in 7, there are few spectral lines associated with graphite to interfere with elements to be determined.

Graphite vs. Carbon

There is much confusion about carbon *vs.* graphite. All too often the names are used interchangeably. Chemically, of course, they are identical. But their crystal structures are different and spectrographically they behave quite differently. Carbon is a far poorer conductor of both heat and electricity and, as a result, it retains more heat. It would, therefore, potentially appear better for analysis, especially of materials with a high melting point. One severe drawback, however, is its extreme hardness and brittleness which makes it almost impossible to machine with ordinary tools. Another disadvantage is that carbon cannot be obtained as pure as graphite. Abroad, carbon is often used despite these shortcomings, especially for the cathode layer technique. In this country, carbon is usually shunned.

Adding to the confusion, National Carbon Company Regular Grade "spectroscopic carbons" are misnamed. They are *graphite* rods and the company has stated that the name will be appropriately changed when the current supply of cartons is depleted. Incidentally, graphite "writes" while carbon does not.

Grades

Since graphite rather than carbon is almost exclusively used in the United States, discussions will be limited to the former. Graphite rods and powders are available in various grades and types. The rods are, first of all, manufactured in varying hardnesses and densities. Thus National rods (produced in one hardness or density) have a hardness somewhere between the United U-1 and U-2. If a spectrographer chooses to machine his own electrodes, he will note these small differences in ease of machining. United also produces a very hard, high-density graphite, U-F4, more difficult to form with the ordinary laboratory cutters.

Spectroscopic graphite is now available in three grades of purity. National so-called Regular Grade (AGKS) is the least pure and least expensive. It has, nevertheless, a total ash content of less than 0.1% so that, by any standard other than spectrographic, it is quite pure. The United Spectro-Tech Grade is

an intermediate grade and has an ash content of less than 0.04%. The National Special Purity Grade (AGKSP) and the United Ultra Purity materials are of about the same high purity. The ash content is immeasurably small in these materials.

The highest purity graphite electrodes are sold with an accompanying analysis report which assigns arbitrary estimates of those elements detected. Purity of these electrodes has improved markedly in recent years. For example, where almost all such material contained traces of vanadium and boron just a few years back, most of it is entirely free of these today. In fact, United claims that its purification process eliminates boron entirely. The elements most likely to occur in high-purity graphite are aluminum, copper, silicon, iron and magnesium. By selection, it is possible to obtain graphite free of one or even more of these elements. Thus silicon as well as boron-free electrodes may be specified. An additional charge of about 15% is made for this selection.

The common elements found in United Spectro-Tech and National Regular Grade graphite are aluminum, boron, calcium, copper, iron, lead, magnesium, manganese, potassium, silicon, silver, sodium, tin, titanium and vanadium. Other elements may be found in certain batches and of course, batches may be entirely free of one or more of the above. Pre-arcng these grades of graphite will purify them to some degree. As stated previously, the total impurity content of Spectro-Tech is considerably below that of the Regular Grade.

There are two basic types of graphite powder supplied by both National and United. Grade SP 1 (National) and UCP-1 (United) are similar and are used for preparing briquets. They are generally mixed with a sample powder and then briquetted. A spark may then be directed to the briquet for the determination of elements at relatively high concentrations (0.1% and above). An unbriquetted powder generally is not sparked. It spatters.

The other grade of graphite powder is either SP 2 or UCP-2. It differs from the former in particle shape. Although it cannot be briquetted, it mixes more readily with other powders and is thus more suitable as a general purpose buffer and diluent.

National Carbon Company normally provides its SP 1 and SP 2 powders in but one particle size. United Carbon Products Co. supplies powders in -100, -200 and -300 particle sizes. UCP-2, -100 mesh material is particularly suitable for semi-quantitative work where it is used as a diluent with unknown powders as well as our Spex Mix. The coarser particles have better mixing properties and have less tendency to fly out of the electrode crater during arcing.

Sizes in General Use

In all purities and hardnesses spectroscopic graphite rods, in twelve-inch lengths, are available in the following sizes:

Nominal Diameter	Finished to
1/8"	.120 ± .002"
3/16"	.180 ± .002"
1/4"	.242 ± .002"

With the exception of the Spectro-Tech Grade, rods are also available in the following diameters:

5/16"	.304"
3/8"	.365"
1/2"	.493"

Whereas the practice in the past has been to provide Regular Grade rods in the sizes to which they were extruded, all spectroscopic rods are now centerless ground down to the values given in the last column above. This standardization has greatly simplified machining operations in the laboratory.

Preforms

The major portion of this paper is devoted to preformed electrodes, both sample and counter, in common use. Here a senseless hodge-podge exists, most of which may be blamed on history. Time was when all spectrographers machined their own electrodes. Multiply the imagination, talent and requirements by the number of us old-time spectrographers and you will arrive at the almost astronomic number of kinds of preforms now in use. No spectrographer will claim that an electrode he uses with a 5/64" deep crater is better than an identical one with a 3/32" deep crater. But to use the latter would involve changes in his working curves with which he would rather not be troubled.

Despite this history, a fair number of preforms have filtered through into common usage. These are available readily and are purified after being machined to exacting tolerances. Most spectrographers use these wherever possible in order to maintain high precision and avoid contamination in their work.

As for designations, no rhyme or reason exists. United started with a brave attempt to label all their cupped electrodes "L" (for lower) and the counter electrodes "U" (for upper). For various reasons, this system was abandoned. The American Society for Testing Materials is now attempting to use a prefix to designate electrodes as shown below:

C	Counter electrode
S	Crater electrodes
PC	Center post electrodes
D	Disc electrodes

Most suppliers have dropped key designations and have finally wound up with nondescript catalog numbers for all preforms.

The most common electrode is a cupped rod (typical is Spex 4002 in the accompanying chart). The crater in this electrode is about average in depth (3/16") and average in diameter (3/16") in a rod 1/4" in diameter. Let us examine the characteristics of this electrode and then discuss the effects of changes.

No. 4002 holds about 100 mg of materials of average density. Spectrographically, this is a large sample and its size aids in minimizing segregation difficulties. By the same token, a complete burn of such a sample may take 2-4 minutes in an ordinary 5-10 ampere arc. Thus, to reduce the time of exposure and therefore the cost of the analysis, a smaller capacity electrode may often be used. Typical of these is 4016 with a 1/16" deep cup. By virtue of its shallow cup, this electrode has a small temperature gradient along its depth during arcing, promoting a complete burn of the sample. In a deeper cup, on the other hand, elements have a tendency to distill selectively. This, of course, is valuable for the determination of a comparatively volatile element in a refractory medium.

There we have two extremes represented by two types of electrodes: the determination of one or more volatile elements in a relatively refractory base; the determination of all elements. In the latter problem, an undercut electrode frequently helps by raising the sample temperature through reducing the heat loss to the stem of the electrode. So, for qualitative and semi-quantitative work, where the spectrographer must insure the detection of all elements, he generally chooses an electrode like the 4000 or 4021.

All the electrodes discussed thus far are 1/4" in diameter, which raises another problem: arc wandering. Throughout the burn, the mischievous dc arc roams aimlessly from one point on the electrode surface to another. The result is poor reproducibility because the spectrograph sees a fluctuating source of illumination. Arc wandering may be reduced by simply restricting the area of the electrode. Accordingly, there is an increasing tendency to employ 3/16" diameter electrodes such as the 4001, 4005 and 4029. Many spectrographers have gone one step further and

are now using 1/8" diameter electrodes (4020). I saw a beautiful set of data recently illustrating the significant improvement in reproducibility which resulted from switching from 1/4" to 1/8" electrodes. The optical set-up here makes use of cylindrical lenses where arc wandering effects are particularly troublesome.

Another approach to diminishing arc wandering is the use of a center-post electrode (4025). The arc remains pinned to the center post during the burning. One disadvantage of this type of electrode is that a great deal of graphite is consumed, the incandescence of which results in background fog on the plate. Moreover, because the arc does not strike the sample, it remains somewhat cool and the time required for a complete burn is extended. Finally, center-post electrodes are rather inconvenient to load.

Many of these difficulties have been overcome through the design of electrodes such as 4003. This has a cup with a shallow depth but a wide diameter which facilitates loading and improves the burn-off simultaneously. Moreover, it is undercut to assure a complete burn. In this regard, it should be pointed out that with the 4003, like many other undercut electrodes, the end point of a complete burn is easily determined. The arc is usually stopped when the cup has burned away and only its supporting stub is seen (dark glasses are, of course, used).

The 4003 electrode and similar ones are widely used for the analysis of petroleum oil ash.

Another type of lower electrode is that devised by Scribner and Mullin (*J. Research Nat'l. Bur. Standards*, 37, 379-89) for their carrier distillation technique. It makes use of an anode cap (4018) mounted on top of a supporting graphite rod (4017). Like the undercut electrodes, the carrier distillation electrode has the advantage of reducing heat losses. By adding a volatile substance (gallium oxide), the investigators showed how impurity elements in a uranium ore could be determined with little interference from the spectrum of uranium.

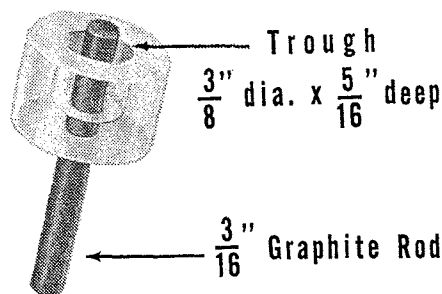
To achieve this carrier effect by another method, a drilled boiler cap (4022, 4023) may be fitted over the top of an electrode. Volatile elements boil out through the small hole in the cap. More refractory ones condense on the inside walls of the cap. Of course, it is possible to combine the anode cap and a boiler cap and theoretically achieve still better separation of volatile from non-volatile materials.

Solutions

Solutions or liquids are frequently analyzed by evaporating them on a flat-topped preformed rod (4024). Such an electrode may be porosified by arcing to its surface for 30 seconds at

6 amperes or the entire electrode may be porosified by heating it in a furnace for several hours at 900°C. For trace-element work, it is preferable to use an unporosified electrode so that the solution does not penetrate it. To the top of the electrode is added a drop of a dilute solution of grease (avoid silicone compounds if silicon is to be determined) in a volatile solvent such as hexane. A drop of an aqueous solution will perch itself on a surface so treated and may be dried by gentle heating in an oven or with an infrared lamp. A micropipette is used to deliver an accurate quantity of liquid to the electrode.

3450 Solution analysis cups

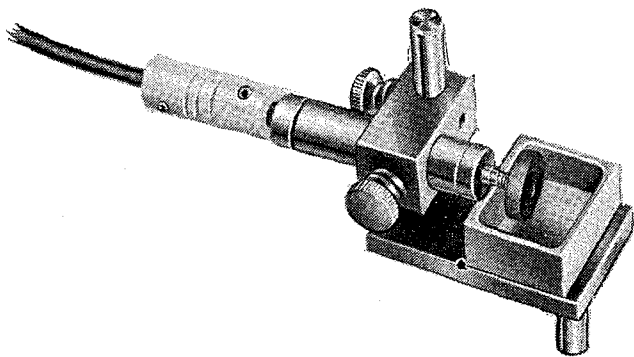


Several more elegant solution methods have been proposed and are common. One is the porous cup technique devised by Feldman (*Anal. Chem.*, 21, 1041). Here the solution is fed into a deep hollowed-out electrode with a thin floor (4014). This is then made the *upper* electrode and a spark is directed to its bottom end. After a few seconds, the spark penetrates the floor and the liquid sprays out into the spark. Several types of porous cup electrodes are available. Some have thick floors (4031) so that intense sparks may be used without danger of the entire bottom falling out. Others are designed with a chamfered bottom (4015) to help center the spark. It is important to prevent the solution from drying out during the burning. Accordingly, for long burnings, a reservoir containing additional solution may be attached to the electrode with rubber tubing.

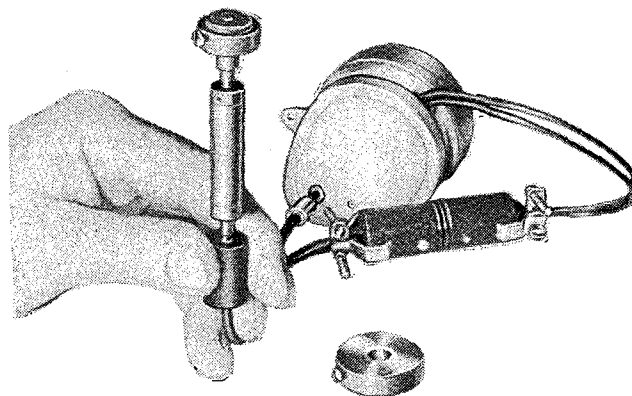
Feldman has also pointed out that concentrated solutions of sulfuric acid attack the graphite, causing the spark to behave erratically. If dilute sulfuric acid cannot be used, he suggests perchloric acid. With the latter, the only precaution necessary is the strict avoidance of organic matter.

Under certain conditions, solutions may have a tendency to seep through the side walls of porous cup electrodes. According to S. Weisberger of Sylvania Electric in Bayside, N. Y., this can be prevented by immersing the electrodes in a very dilute solution

COMBINATION ANALYZER



No. 3400 Combination Analyzer as set up for solution analysis.




















No. 3400 Combination Analyzer shown as it would be used for platform electrode analysis.

Also shown is the Table Adapter No. 3402.

A graphite mandrel is now available for corrosive liquids.

PERFORMED ELECTRODES

CONVERSION CHART

	Spex	ASTM	National	United	Price per 100	United Spectro-Tech (Prices on request)
	4000	S-12	L-3912	100-L	\$20.00	ST-508
	4001		L-3903	101-L	20.00	ST-510
	4002	S-8	L-3900	103	20.00	ST-505
	4003	P-2	L-3948	104-L	25.00	
	4004		L-3906	105-S	18.00	
	4005	S-14	L-3909	105-D	18.00	
	4006	C-5		100-U	18.00	ST-500
	4007	C-8	L-3960	101-U	18.00	
	4008	C-7	L-3963	104-U	20.00	
	4009			105-U	18.00	ST-450
	4010	C-2	L-3966	108	18.00	ST-502
	4011	D-1	L-4075	106	14.00	
	4012	D-3	L-4078	1907	16.00	
	4013		L-3936	201	22.00	
	4014		L-3927	203	22.00	
	4015		L-3933	204	20.00	
	4016	S-5		4196	20.00	ST-504

12" GRAPHITE RODS — PRICE LIST

	1/8"d.	3/16"d.	1/4"d.	5/16"d.
National Reg. Gr.	\$13.75/100	\$13.25/100	\$14.75/100	\$17.75/100
United Spectro-Tech	18.00/100*	20.60/100*	23.20/100*
National Special Gr.	45.00/50	28.75/25	19.80/15	12.32/8
United Ultra-Purity	21.60/24	13.80/12**	15.84/12**	18.48/12**

PREFORMED ELECTRODES

CONVERSION CHART

Spex	ASTM	National	United	Price per 100	United Spectro-Tech (Prices on request)	
4017	S-1		1964	\$14.00		
4018	S-2	L-4024	1990	14.00		
4019	C-1	L-4036	1992	14.00		
4020			5440	18.00		
4021	S-4	L-4012	1988	20.00		
4022		L-3915	300	25.00		
4023			301	25.00		
4024	C-3	L-3921	107	16.00	ST-507	
4025		L-3939	102	22.00		
Ad 4026			2022	24.00		
4027	D-2	L-4072	861	14.00		
4028	D-3	L-4081	1909	16.00		
4029		L-4000		18.00		
4030		L-4006		18.00		
4031		L-4048	1994	22.00		
4032			2025	22.00		

GRAPHITE POWDER — PRICE LIST

United UCP-1† or National SP 1 (for briquetting)

United UCP-2† or National SP 2 (for conducting and buffering)

1 oz. \$8.00
1/4 lb. 30.00

1/2 lb. \$58.00
1 lb. 96.00

5 lb. ~~55.50~~ \$55.00/lb.

*These prices are progressively reduced as quantities are increased.

**Specify U-1 (medium hardness) or U-2 (soft).

†Available in -100, -200 and -300 particle sizes.

of grease before loading. He uses 50 mg. of Apiezon dissolved in 100 ml. of petroleum ether. Gentle drying removes the solvent.

Another solution method utilizes a Lucite cup around a 3/16" diameter graphite electrode (above). The solution is placed in the cup and, as the spark plays on the electrode it is porosified, causing the solution to feed upwards by capillary action.

Both the porous cup and the Lucite cup systems have one failing. Suspended matter is filtered out and its spectrum does not register. To overcome this, the "rotating disc technique" may be used. The 4011 disc is 1/2" in diameter by 1/8" thick and is suitable for use with low-intensity sparks on non-inflammable solutions. When solutions with a low flash point are to be analyzed, the use of a thicker disc (4027) often prevents ignition. These disc electrodes are mounted in several ways. With the Spex Combination Analyzer (3400), they are either pushed over a stainless steel shaft or over a graphite tapered mandrel (4032). The latter is especially useful with corrosive solutions or hot sources. With another rotating disc accessory, a longer tapered graphite rod is employed as the shaft (4026).

Still another way in which suspended matter in solution may be analyzed is with the rotating platform electrode (platrode). This is a button 1/2" in diameter with an annular channel machined) from high-density graphite and is recommended for the into this channel and dried or, if organic compounds are present, ignited. The platform is then rotated in a horizontal plane at 1-10 rpm in an instrument such as our Combination Analyzer. There are two generally-used rotating platforms, both having the same physical dimensions and appearance. One (4012) is appreciably porous to light oils but is preferable for the analysis of heavy oils. The other (4028) is molded (rather than machined) from high-density graphite and is recommended for the analysis of light oils. It is an extremely hard-surfaced, non-porous electrode.

The "rotating platform technique" is rapidly gaining acceptance for the analysis of flammable liquids or solutions containing suspended matter. By exposing a large surface area and through rotation, segregation errors are reduced significantly.

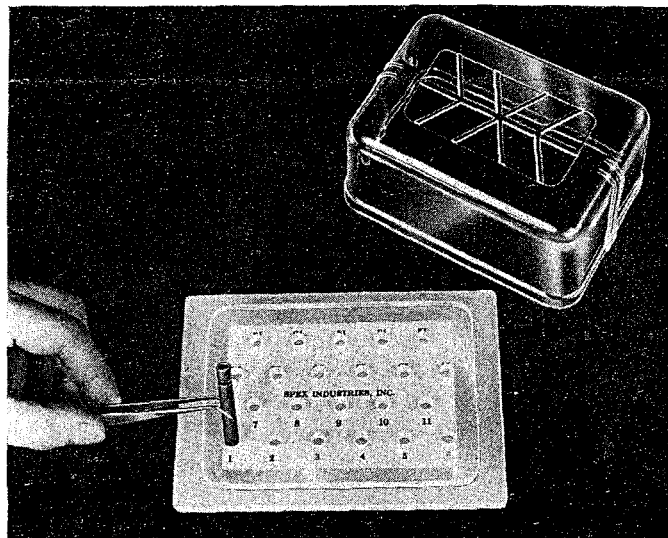
A less well-known solution method is that developed by E. DuBois of Spectrochemical Laboratories, Pittsburgh, Pa. Here the solution is sprayed between two graphite electrodes as they are sparked. The spray first permeates the electrodes before being excited. D. O. Landon, of Sperry Gyroscope Co., Great Neck, N. Y., has found the United U-2 rods, 1/4" diameter suitable for this work. The rods are rounded to a 1/8" radius and the gap separation is 3 mm. Landon has carried out the analysis of many samples of Monel with this technique and has determined all elements even those present at 30-70% concentration. His statistical studies have substantiated DuBois' claims that excellent precision and accuracy are obtained with the technique. Landon uses the flame photometer atomizer from a Beckman DU, feeding argon instead of a combustible gas into the atomizer. This is mounted about 30 mm from the electrodes. A high-inductance spark was found to yield exceptionally good sensitivity.

As indicated earlier, the descriptions above do not, by any means, exhaust the sample electrode types now in use or the many modifications made by ingenious spectrographers. For example, Publicover (*Spex Speaker*, Vol. 1, No. 3) has devised a system for determining traces of volatile impurities in metals. He uses a deep-cupped electrode and extends this further with a paper tube. This is filled with metal chips. Upon arcing, the paper burns away, but the surface tension of the molten metal keeps it standing above the electrode. Using this technique, a large amount of material is arced, enhancing the detection of many volatile elements by at least an order of magnitude.

One bother in spectroscopy is direct handling of organic materials. By burning, they reduce the temperature of the arc below the point where spectral energy is released. Often, organic matter may be placed at the bottom of a deep-crater electrode. Removed a distance above the burning substance, the arc thus attains a high temperature.

Counter Electrodes

So much then for the sample electrodes; now let's discuss the upper. Generally, the counter electrode is a graphite rod



Plastic Electrode Stand

PLASTIC ELECTRODE STANDS

In response to your many requests, we are now manufacturing plastic electrode stands designed for loading up to 22 electrodes. Three stands are available for 1/4" d., 3/16" and 1/8" d. electrodes.

As pictured, the base of the stand is of Plexiglas and has 22 stations, each numbered to avoid mix-ups. The holes are so spaced that one of our funnels may be placed over an electrode without interference from an adjoining one. The base and clear plastic dust cover will resist mineral acids which might be accidentally spilled in filling an electrode.

In order to distinguish among two or three stands with which your technician is working, they are available in three colors: white, black and red.

- | | | |
|------|---|---------|
| 3051 | Plastic Electrode Stand, for 1/4" electrodes,
white, black or red base (specify color) | |
| | Each | \$20.00 |
| 3052 | Plastic Electrode Stand, for 3/16" electrodes,
white, black, or red base (specify color) | |
| | Each | \$20.00 |
| 3053 | Plastic Electrode Stand, for 1/8" electrodes,
white, black or red base (specify color) | |
| | Each | \$20.00 |

with a flat or pointed end. A sharp point helps direct the initial dc arc to the center of the sample electrode but, burning away so rapidly, the angle of the point is not at all critical. In general, 1/8" pointed preforms (4019) are used with 1/8" sample electrodes, 3/16" pointed or rounded electrodes (4009) paired with 3/16" lowers and 1/4" (4006) likewise.

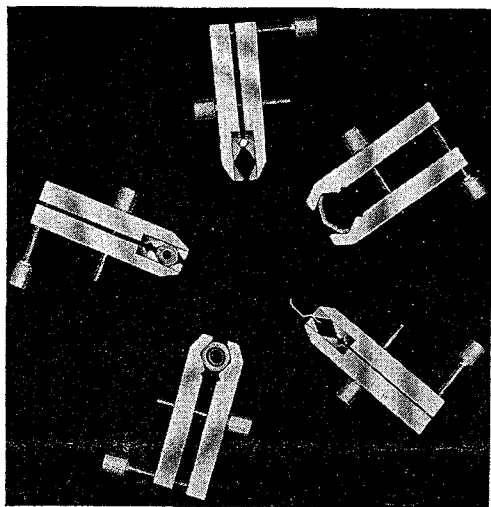
For spark work, a pointed electrode is normally employed. The angle, however, is generally greater than that used for arc work, e.g., a 60° included angle point on a 1/4" rod (4010). It has been shown that, if this angle is increased even as high as 175°, the sampling area is increased correspondingly. For this reason, there is a tendency to use these blunt-pointed electrodes for analyzing metal discs where micro segregation occurs.

There is a preference for an undercut electrode in certain arc work to reduce dissipation of the arc heat. Two types are fairly common, one with a disc end (4007) which encourages arc wandering and, therefore, a more even distribution of the heat over the sample; the other undercut counter electrode has a narrow (4008) tip to restrain arc wandering while reducing heat leakage.

Summary

In this article, we have attempted to bring spectrographers up-to-date on the rather involved story of spectroscopic graphite. It goes without saying that it is in the nature of a progress report. Further advances in the purity of graphite will surely be made and additional special-purpose preforms will be designed in the years ahead.

—A. J. MITTELDORF.



THE PETREY STAND SAMPLE CLAMP

grips small and/or irregular samples which alone cannot be mounted. Spectrographers frequently improvise using "baling wire and string" to mount such samples directly above the lower electrode and in the exact plane of the Petrey table. With the Sample Clamp, positioning is practically automatic. The forward screw is tightened around the sample while it is placed on a flat surface. The photo shows the undercut on one side of the clamp which permits tiny samples to be held without risk of sparking to the clamp instead of the sample. Constructed of chromium-plated brass, the clamp is an excellent conductor of electricity and heat. It will retain its attractive appearance for years even in laboratories where chemical fumes are a problem.

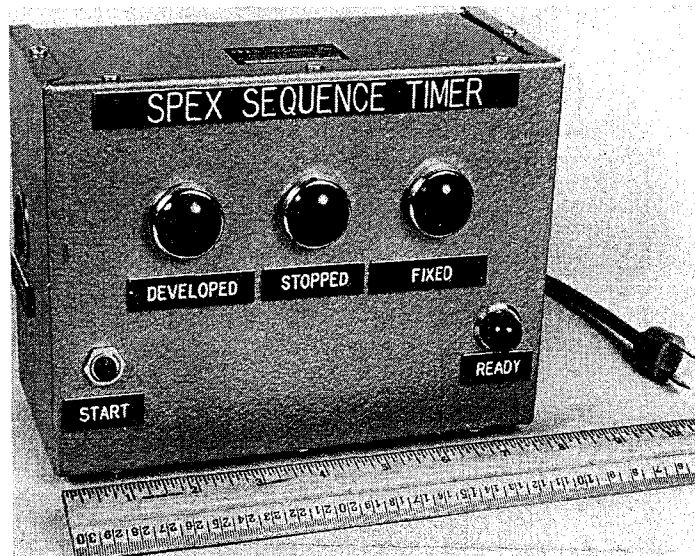
3300 Petrey Stand Sample Clamp.
Each \$32.00

THE SPEX-OWENS SEQUENCE TIMER

Especially in production laboratories, there has been a real need for a timer to control the entire photographic processing from development through drying of the emulsion. Although many spectrographers have shown that the photographic plate is a serious source of error in spectrographic analysis, some laboratories do not have the facilities for reducing the error. Especially when inexperienced personnel are employed in the dark-room, it is an excellent idea to have each of the operations controlled with a fool-proof timer. Designed by L. E. Owens, the Sequence Timer meets these requirements. It indicates the conclusion of each step in the photographic processing with a signal light or buzzer. Its sequence is as follows:

At the conclusion of its cycle, a "ready-to-operate" pilot lights up. The developing machine which is plugged into the outlet on the Sequence Timer starts agitating as soon as a button is pressed. At 2 min. 45 sec., a warning buzzer sounds to remind the operator to stand by. At 3 min. 0 sec., the first pilot lights telling the operator to transfer the plate to the stop bath. The next pilot lights in 15 sec. to indicate transfer to the fixing solution. This is followed by the third pilot light which goes on after the plate is in the hypo for 30 sec. Finally, the "ready-to-operate" pilot lights after the plate is washed for 1 min. 15 sec.

This cycle is particularly chosen for SA #1. In the event that other intervals are required, these must be preset at the factory. Any four successive time intervals totalling 5 min. or less may be specified. In addition, we shall be glad to quote on special instruments in which the total time is greater than 5 min.



Spex-Owens Sequence Timer, 115, 60 cy ac, 5 min. total timer with four sequence indications as given above; attractively finished in hammered grey sheet metal case.

Each \$150.00

Spex-Owens Sequence Timer, same as above but with four successive intervals totalling 5 minutes or less but different from those described in the text, please specify.

Each \$165.00

Oops, our error—May we publicly thank so many of you for calling attention to an error of inversion on page 2 of the last issue of the *Spex Speaker*, Vol. 2, No. 2. In describing how standard G-1 is prepared, we should have stated: It is made by mixing 0.100 weight units of Spex Mix with 1.24 weight units of graphite.

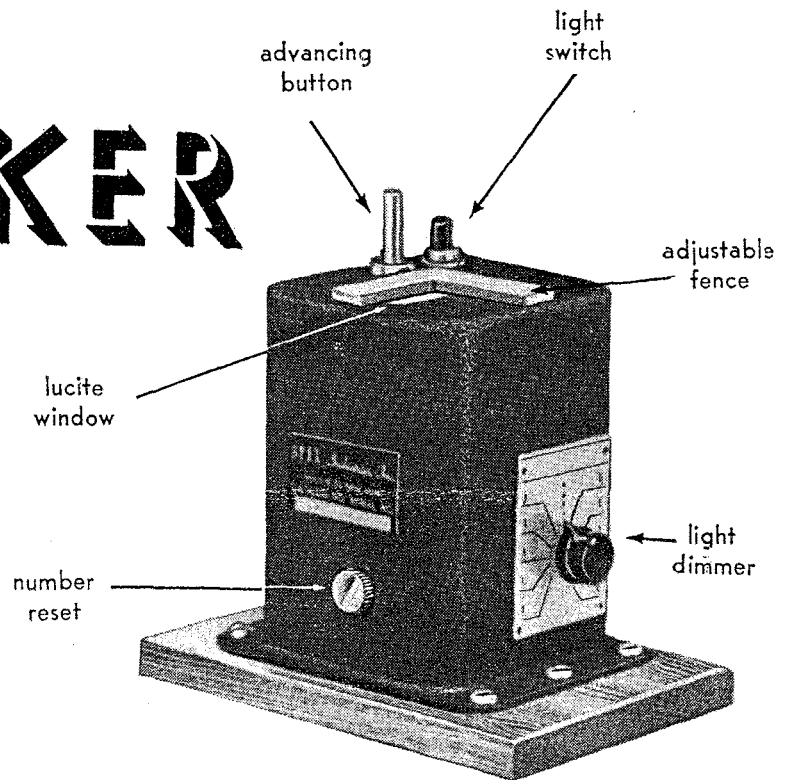
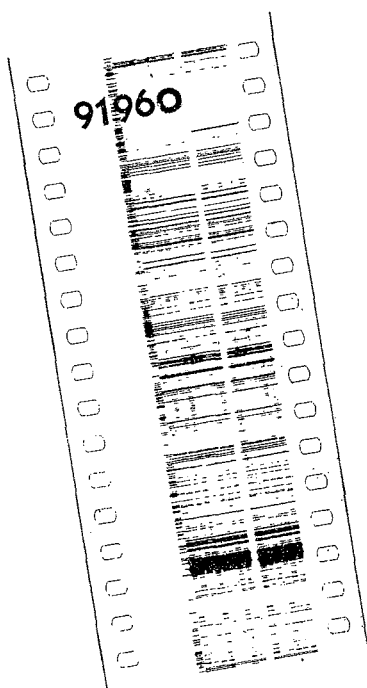
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New Model

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for | SPECTROSCOPY, X-RAY DIFFRACTION,
ELECTRON DIFFRACTION
METALLOGRAPHY, NUCLEAR PHYSICS,
MICROSCOPY AND PHOTOGRAPHY