Seeing The Very Small

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Scanning Electron Microscope Demonstration
By Richard J. Nelson with SEM images by Brian Dearden

During the annual Kids Day at the Alfred Mann Foundation, Brian Dearden prepared four common "powders" to show that normal appearance is not what it seems. The scanning electron microscope was used to show what each powder "particle" looks like under high magnification. Brian demonstrated how the SEM magnifies using the powders as subjects.

The four Petri dishes containing the four powders are shown figure 1 at the right as they were shown to the visitors who were asked to describe what they looked like.

A close up photo of each Petri dish is shown in figures 2 through 5. An even closer view of each of the "powders" is shown in figures 6 through 9. Figures 1 - 9 were taken with the Nikon Coolpix 995 digital camera. Figure 10 shows Intel QX3 computer microscope (designed to be a child's toy) views at magnifications of 10, 60, & 200X. The scanning electron microscope view of each of the powders is shown in figures 11 - 14.
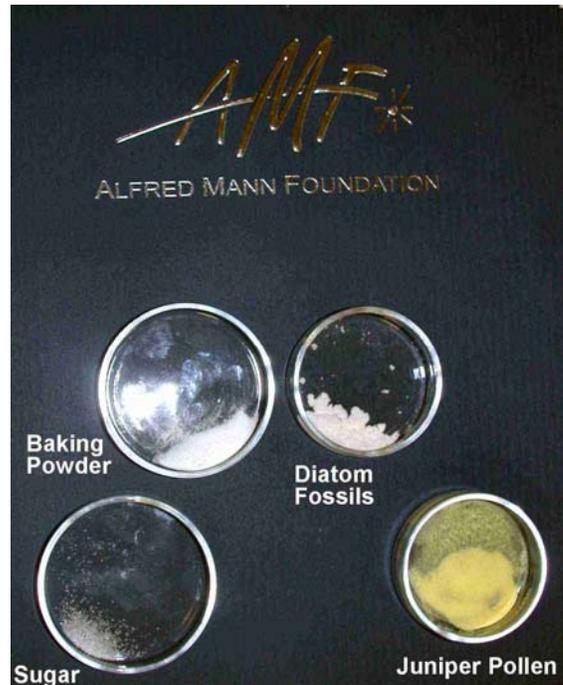

Fig. 1 — Petri dishes containing four powders.

<u>Sugar</u> is easily recognized as having a crystalline shape with the naked eye but it takes some form of magnification such as a microscope to clearly see its shape or structure. For the science minded, the experiment of growing rock candy on a string from a sugar solution (if grown slowly) will show the crystal structure in a much larger form. Sugar has unusual qualities, which are exploited in the making of cakes, muffins, biscuits, and cookies, bread, crackers, ice cream, and a large variety of candies and confections. These unusual temperature related properties are especially used to produce simple goodies such as rock candy to more complex things such as soft cotton candy.

<u>Baking Powder</u> is not a single material but a mixture of three powders. One is an acid, typically cream of tartar. Another is a base, typically baking soda. The third is filler, typically corn starch. When flour is used to make dough, which is baked to make the end product, the result is considered tastier if it is light and fluffy. To make bread light and fluffy requires that air spaces be put into the bread as it bakes.

The spaces in bread are typically created with the addition of yeast, which slowly releases carbon dioxide during the two or three hour baking process. Baking powder performs the same process for things like cakes, muffins, biscuits, and cookies. Baking powder reacts with water to more quickly release carbon dioxide to create the fluffy texture of these baked items in a much shorter time.

Cream of tartar, also know as tartrate salt, has the chemical formula $KHC_4H_4O_6$. The chemical formula shows that cream of tartar is made of potassium, hydrogen, carbon, and oxygen.

Baking soda, also known as sodium bicarbonate, has the chemical formula $NaHCO_3$. The chemical formula shows that baking soda is made of sodium, hydrogen, carbon, and oxygen.

Cornstarch is an organic material and like all organics there is no shortage of variations. Cornstarch is a polysaccharide. As a food material it is approximately composed of Carbohydrates (85 to 90%), Protein

<0.1%, Fat 0.2%, and Crude Fiber 0.1%. You may buy many variations of cornstarch and the corn refiners association describes cornstarch as follows.

Starch is one of nature's major renewable resources and a mainstay of our food and industrial economy. Basic consumer necessities such as paper and textiles are major uses for corn starch in sizing, surface coating and adhesive applications. Corn starches, and their cousins dextrins (a roasted starch), are used in hundreds of adhesive applications. Special types of starches are used in the search for oil as part of the "drilling mud" which cools down superheated oil drilling bits. Other key uses of starch in American industry are as flocculating agents, anticaking agents, mold-release agents, dusting powder and thickening agents.

Literally thousands of supermarket staples are produced using both regular and specially modified starches. Many of today's instant and ready-to-eat foods are produced using starches which enable them to maintain the proper textural characteristics during freezing, thawing and heating. Other starches are the backbone of instant pie and pudding fillings which require little or no cooking compared to traditional formulations.

The most promising new market for corn starches is as raw material for the production of industrial chemicals and plastics which are today made from petroleum feedstocks. As petroleum supplies dwindle or become less reliable, the importance of an abundant source of basic industrial chemicals takes on new proportions. Corn industry scientists are at work on new systems for producing industrial necessities from the versatile corn plant

Diatom fossils are very tiny water creatures many millions of years old that have been preserved in large quantities from sea or lake beds. Their skeletons are often known as diatomite or diatomaceous earth. This mineral was formed as ancient diatoms died and settled to the bottom of lakes or oceans. Today, they form large deposits of white chalky material, which is mined for use in cleansers, paints, filtering agents, and abrasives. At one time many types of toothpastes contained bits of fossil diatoms.

Juniper Pollen is a living material that plants use to reproduce. It is often the cause of allergies in people.

Fig. 2— Sugar in a Petri dish.

Fig. 3—Baking powder in a Petri dish.

Fig. 4 — Diatom fossils in a Petri dish.

Fig. 5 — Juniper pollen in a Petri dish.

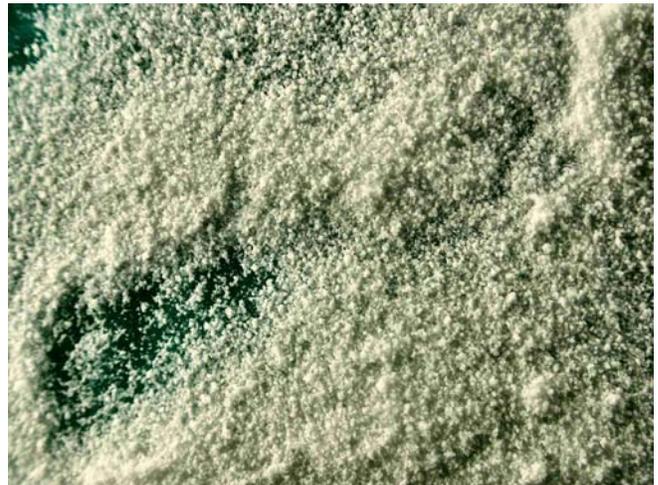*Fig. 6 — Sugar in a Petri dish close up view.*

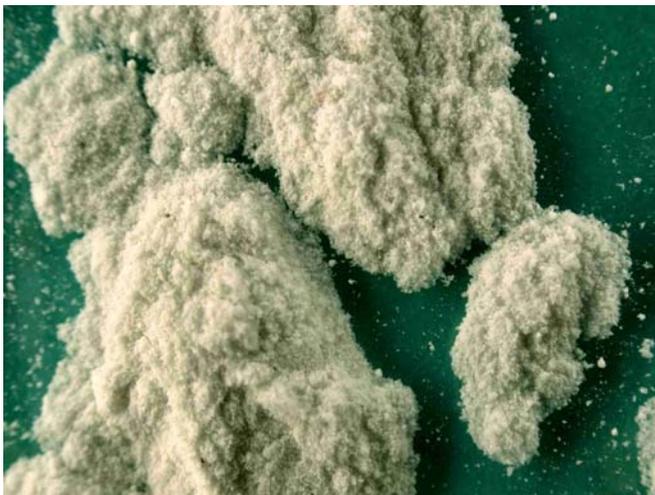*Fig. 7—Baking powder in a Petri dish close up view.*

Fig. 8— Diatom fossils in a Petri dish close up view.

Fig. 9 — Juniper pollen in a Petri dish close up view.

QX3 Microscope Images

The QX3 Microscope is an inexpensive child's toy, one of four products that Intel designed for the scientific toy market in 1999. The product line was a marketing failure and Intel soon abandoned the toy the business. The QX3's were liquidated, often selling in the $40 range. The plastic lenses did not produce a sharp image but the projection (via a slow USB interface) on a computer screen makes it a convenient desktop microscope for the less demanding applications such as viewing printer outputs, very small print, etc. The four powders were viewed at the three "magnifications" the QX3 offers. An LED flashlight added to the QX3 illumination for the 200X images.

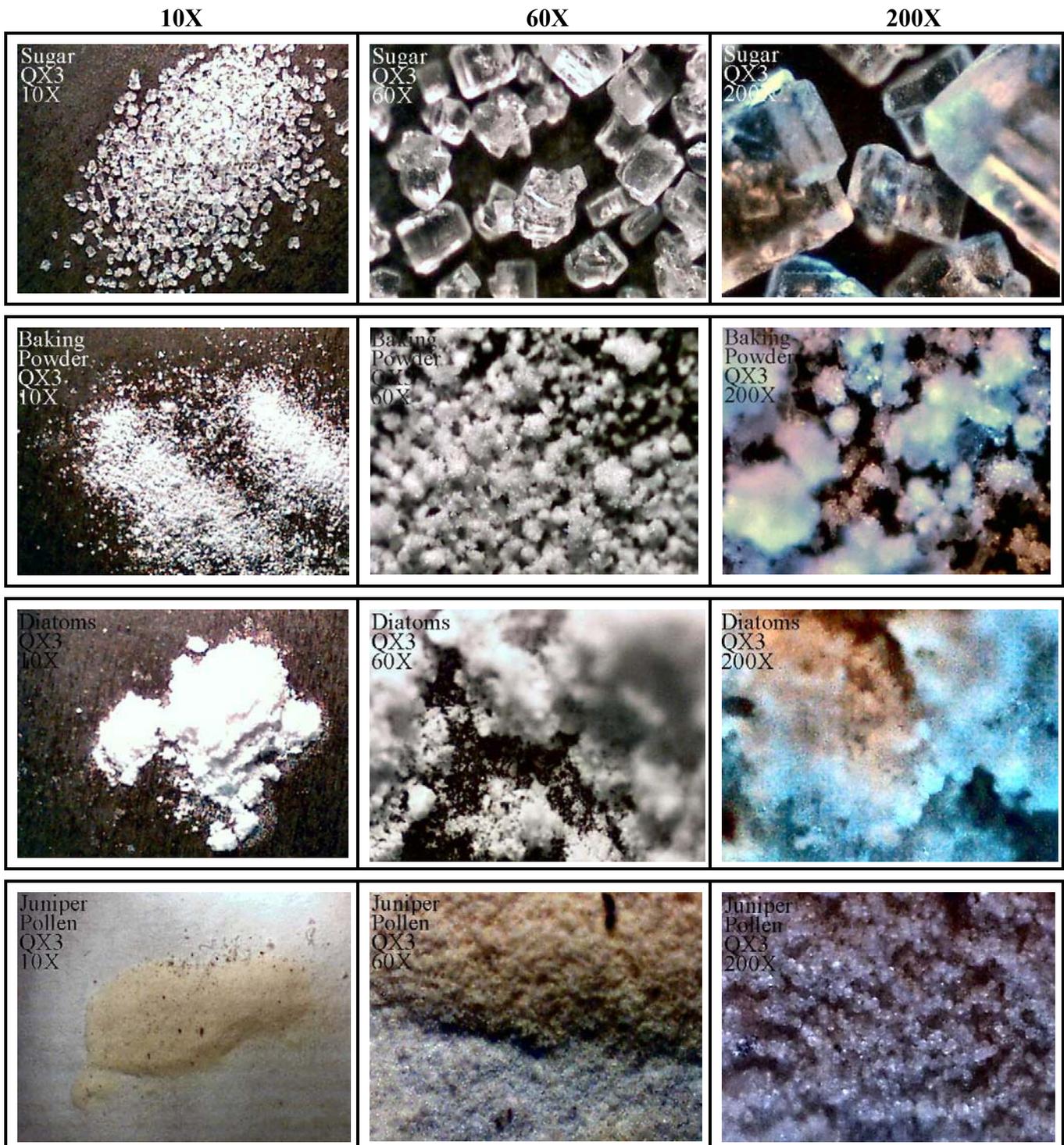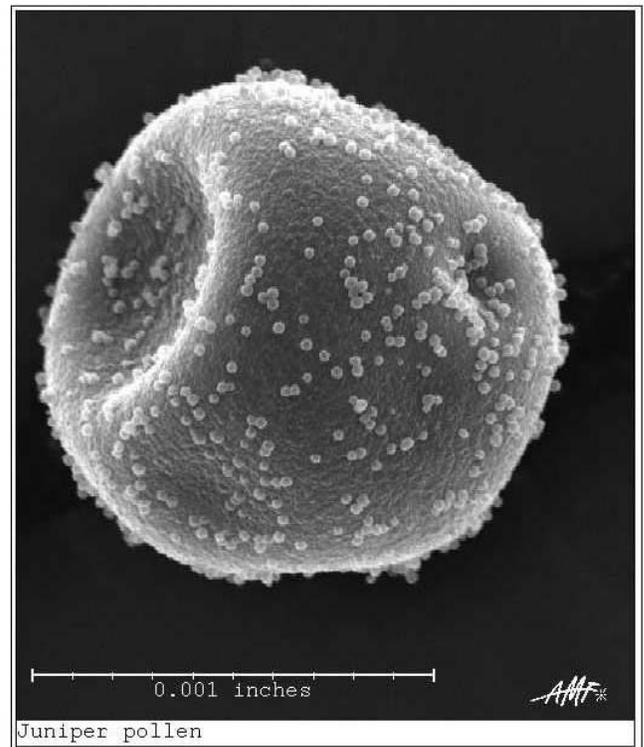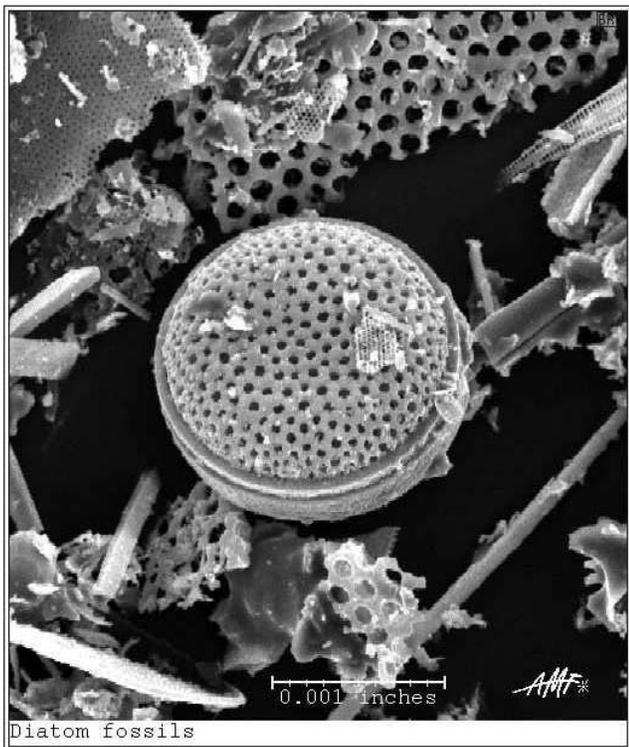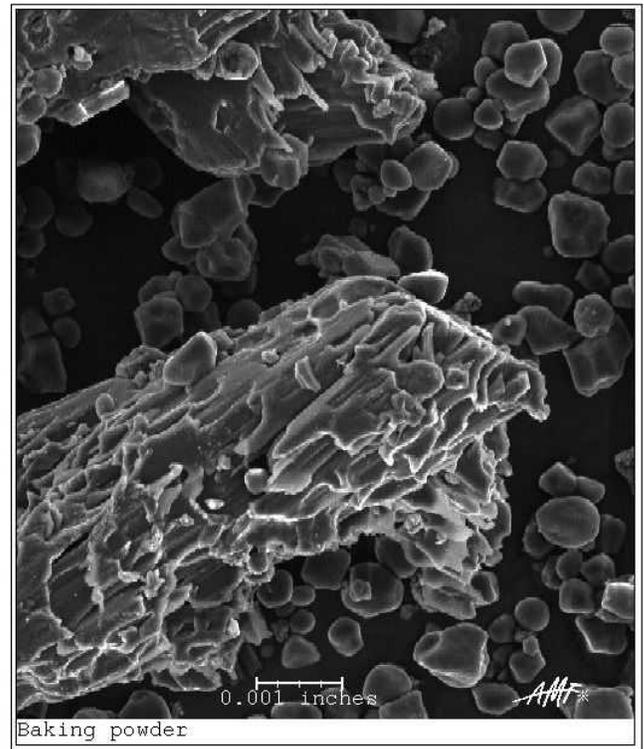| 10X	60X	200X

Figure 10 — QX3 images of the four demonstration powders shown at 10X, 60X, and 200X QX3 magnifications.

SEM Images of Common "Powder" Materials Around The House

Figures 11 -14. SEM images of the four powers shown in figure 1.

Litz Wire Example

Suppose you have a problem with a special wire being used for winding a coil of a medical product. The wire is sterilized in an autoclave and you need to determine several things about it.

1. The wire is specified as Litz wire, which is comprised of 1,000 strands of 44-gauge polyethylene coated copper wire. How may you confirm these specifications?

2. How does the wire stand up under the heat and pressure exposure of steam sterilizing? How does it look after five cycles through the autoclave? Is the insulation cracked, split, chipped or pealed?

One method of answering these questions is to look at the Litz bundle at various magnifications. Refer to the following images taken with a Scanning Electron Microscope.

1. Can you confirm that the bundle is 1,000 strands?
2. Can you confirm that the wire is indeed 44 Ga.?
3. Are you convinced that the insulation is not affected by five cycles of Autoclaving?

If you had this problem on a daily production basis there are more refined methods of obtaining the data. You would cast the wire in a small plastic "hockey puck" block (about 2" in diameter). You would section, and polish it, and then perform an SEM scan. The appropriate software and hardware (not seen at the right in the photo) would automatically analyze each wire and determine the material, shape, variance in shape, diameter, and number. This is done by image analysis software and by measuring the energy given off by the sample as it is being scanned. Of course the hardware and software for doing this is very expensive - hundreds of thousands of dollars for the better products.

AEMF Scanning Electron Microscope

Fig. 15 – Older style SEM that is quite "labor intensive" compared to more modern "production" instruments.

End View Of A Litz Wire Bundle

This view doesn't show all of the strands in the bundle but you may see how a view of a split grouping of the strands would allow you to accurately count the strands to verify that there are actually 1,000 strands. The white-boxed area is to be magnified further. Magnification as shown below is about 65x.
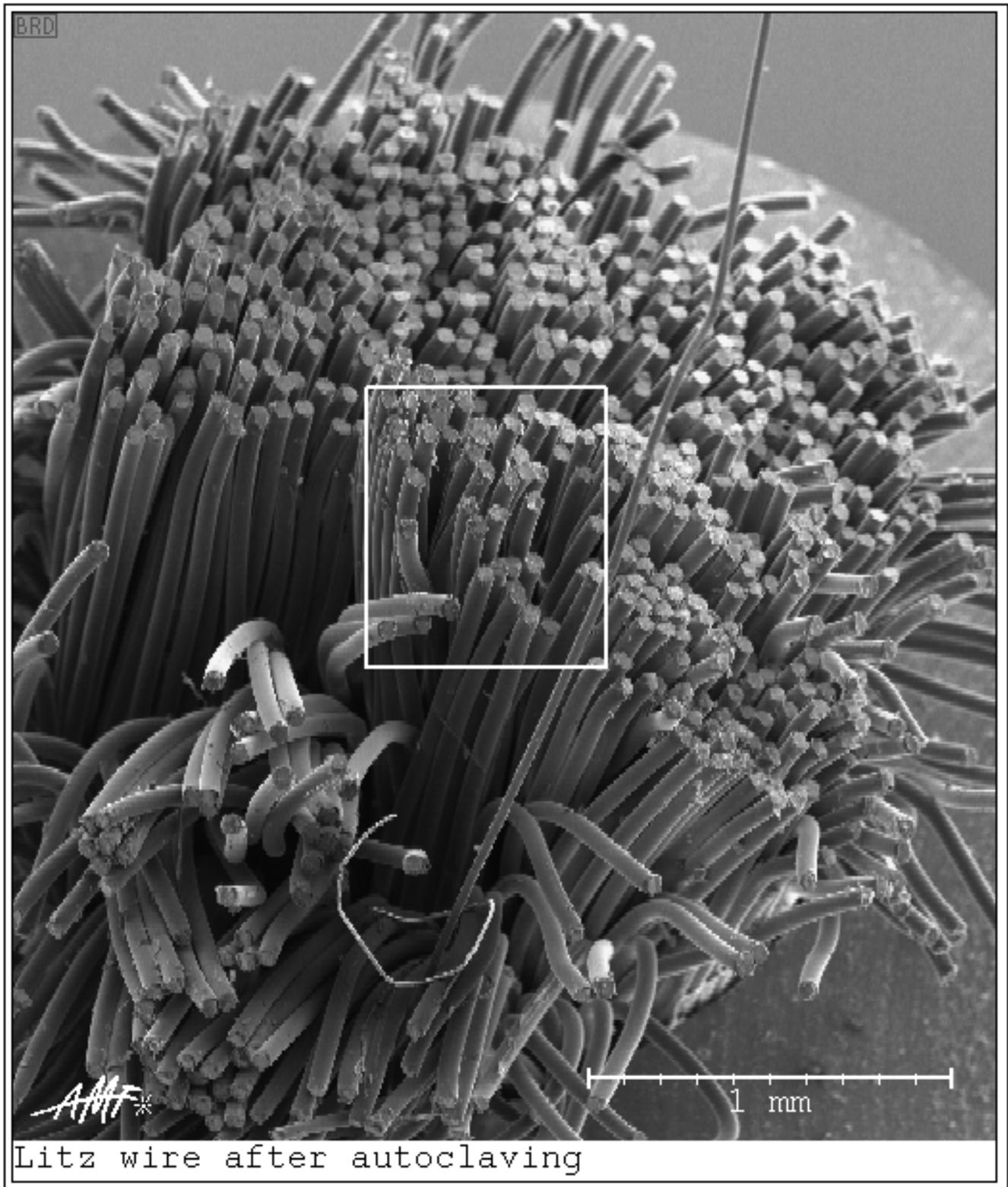
Figure 16 – SEM view of part of the end of a bundle of 44 Ga. copper wires used to wind a coil.

End View Of A Litz Wire Bundle Magnified Further

The strands are magnified further to see how the insulation was affected by the autoclaving. The white boxed area is magnified further. Magnification as shown below is about 280x.
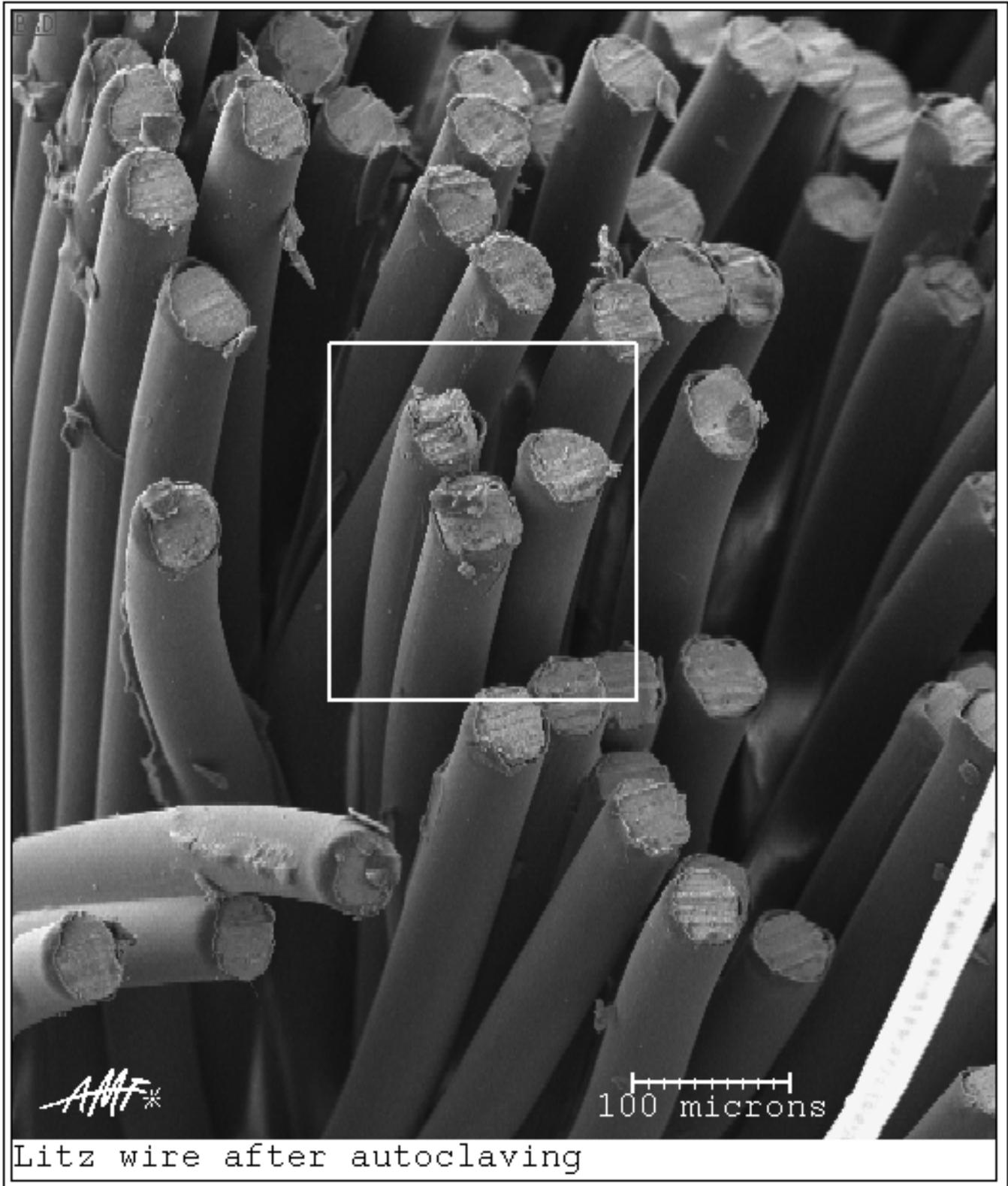
Figure 17 - Further magnification of the bundle shown in figure 16 within the area shown in the box.

End View Of A Litz Wire Bundle Magnified Even Further

The insulation may be examined in detail. Clearly the autoclaving does not affect the insulation of the Litz wire. Let's confirm the wire size used for the bundle. See the next two pages for measurement information. Magnification as shown below is about 940x and represents the upper limit of a normal optical microscope. Of course you would have color, but not the depth of field or sharpness of the SEM.
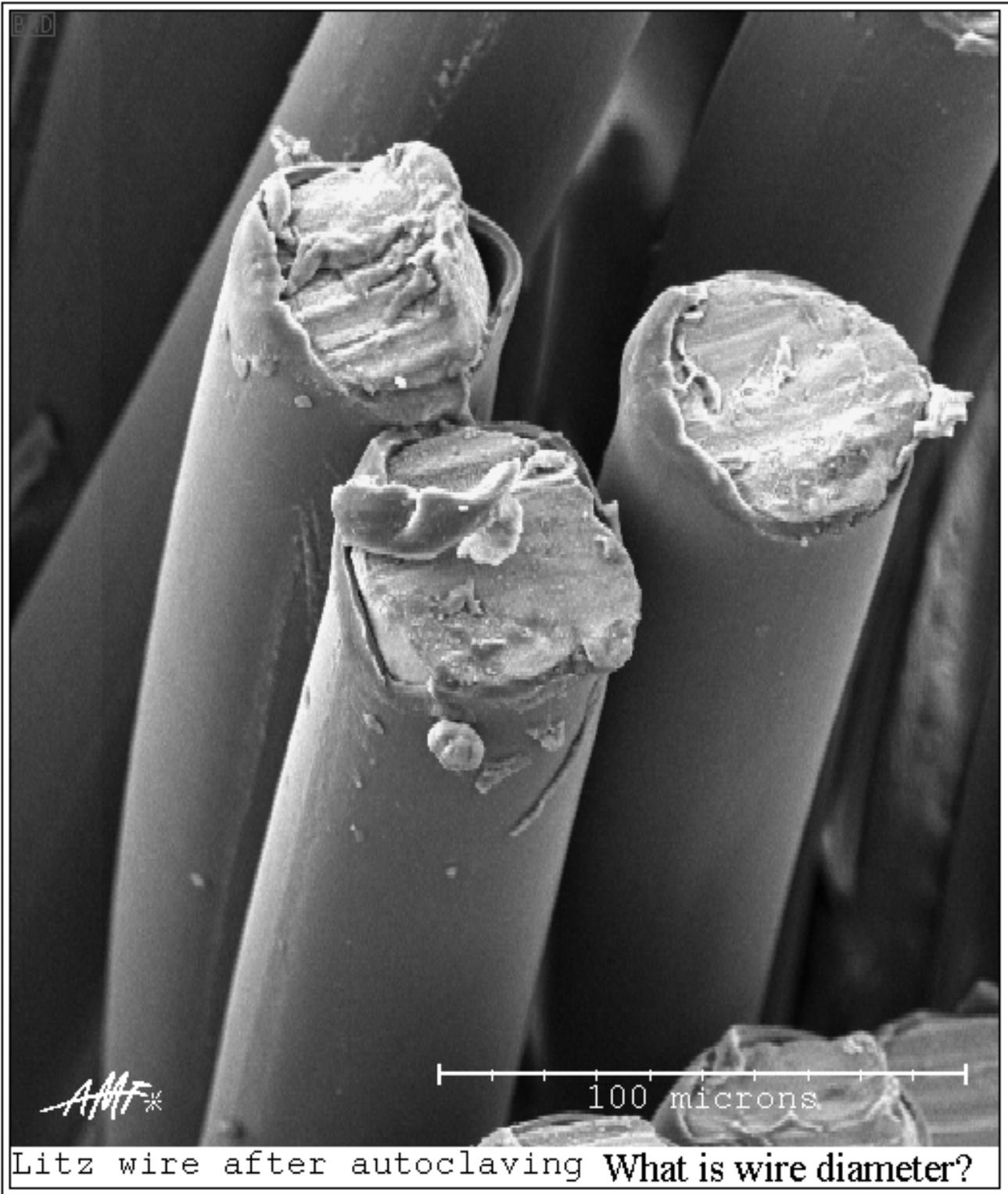

Figure 18 – Further magnification of the litz wire bundle shown in figure 17 within the area shown in the box.

Table 1 - Common Engineering and Scientific Length Units

Angstrom Å	One ten thousands of a micron. 0.0001 micron. 0.00000393700787402 Mil.	
Micron μ	One millionth of a meter. 10,000 angstroms. 0.001 mm. 0.0393700787402 Mil.	Human hair* is 17 to 181 microns. ≈ 100 μ
Mil	One thousandth of an inch. 25.4 microns. 254,000 angstroms. 0.0254 mm.	Human hair* is 0.7 to 7.1 mils. ≈ 4 mils
Millimeter mm	One thousandth of a meter. 39.37 mils. 1,000 Microns. 10,000,000 angstroms.	
Nanometer nm	One millionth of a millimeter. 10 Angstroms. 0.000039700787402 Mil.	Visible light wavelength is 750 to 400 nm.

* A human hair varies greatly. See http://hypertextbook.com/facts/1999/BrianLey.shtml as a resource. The hair is larger closer to the root, it is affected by humidity, time of year, age, and race of the individual. The number given as ≈ is a good average "round" number.

Many authors, however, actually use 1 mill because it is a nice round number and not entirely wrong. Usually you may only know this by a little detective work in reading the article that references the size of a "human hair."

From: http://hypertextbook.com/facts/1999/BrianLey.shtml

Diameter of a Human Hair

The Physics Factbook

Edited by Glenn Elert -- Written by his students

An educational, fair use website

Bibliographic Entry	Result (w/surrounding text)	Standardized Result
Piezo Technology. Epson (UK) Ltd.	"45 microns, 2 times smaller than the diameter of a human hair and close to the limit of resolution for the human eye"	90 µm
Denny R's Homepage. Denny & Gayle Rossbach. Palmdale, CA.	"Diameter of a human hair inches: 0.001; centimeters: 0.00254"	25.4 µm
Why Choose A Water Treatment System? Aqua-Fresh Drinking Water Systems, Inc.	"Particulate contaminants including asbestos, rust, sediment, dirt, and scale as small as 0.2 microns (1/300th diameter of a human hair). "	60 µm
Hair - Important Facts About Hair. CAQTI Cosmetics, Inc.	"Flaxen hair is the finest, from 1/1500 to 1/500 of an inch in diameter...and black hair is the coarsest, from 1/450 to 1/140 of an inch."	17 - 50 µm (flaxen) 56 - 181 µm (black)

Hair can be found all over human body, except for the palms of hands and at the soles of feet. The purpose of hair is protective: the hairs on the body keeps a person warm, nose hairs prevent dust and dirt from entering the respiratory system, and eyebrows prevent sweat from entering the eyes.

The diameter of a human hair does not have a standard value since different people have different hair structures. Your genetic makeup can cause the width of your hair to differ from that of other people. Hair color is also a big factor. Black hair is thicker than is red hair. The weather can also affect the diameter of a hair strand. As the weather gets warmer, the diameter of body hair increases. Age is another factor. Babies and young children have finer hair than adults. As a person grows up, their hair becomes thicker and stronger. Another factor is that, the closer to the root of the hair, the thicker a strand of hair would be.

In my research, I have found the diameter of human hair to range from 17 to 181 µm (millionths of a meter).

Brian Ley -- 1999

Table 2 – Dimensions of Copper Wire

COPPER MAGNET WIRE DATA

SIZE (AWG)	DIAMETER* (INCHES)			RESISTANCE** (OHMS PER 1000FT. AT 20°C)			FEET PER POUND	POUNDS PER 1000 FT.	CIRCULAR MILS	SIZE (AWG)
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.			NOMINAL	
4	.2023	.2043	.2063	.2437	.2485	.2534	7.915	126.3	41740	4
5	.1801	.1819	.1837	.3073	.3134	.3197	9.984	100.2	33090	5
6	.1604	.1620	.1636	.3875	.3952	.4031	12.59	79.44	26240	6
7	.1429	.1443	.1457	.4885	.4981	.5079	15.87	63.03	20820	7
8	.1272	.1285	.1298	.6156	.6281	.6410	20.01	49.98	16510	8
9	.1133	.1144	.1155	.7774	.7924	.8079	25.24	39.62	13090	9
10	.1009	.1019	.1029	.9795	.9988	1.019	31.82	31.43	10380	10
11	.0898	.0907	.0916	1.236	1.261	1.286	40.2	24.9	8226	11
12	.0800	.0808	.0816	1.558	1.589	1.620	50.6	19.8	6529	12
13	.0713	.0720	.0727	1.962	2.001	2.040	63.7	15.7	5184	13
14	.0635	.0641	.0647	2.477	2.524	2.572	80.4	12.4	4109	14
15	.0565	.0571	.0577	3.115	3.181	3.249	101	9.87	3260	15
16	.0503	.0508	.0513	3.941	4.019	4.099	128	7.81	2581	16
17	.0448	.0453	.0458	4.944	5.054	5.167	161	6.21	2052	17
18	.0399	.0403	.0407	6.261	6.386	6.514	203	4.92	1624	18
19	.0355	.0359	.0363	7.871	8.047	8.229	256	3.90	1289	19
20	.0317	.0320	.0323	9.941	10.13	10.32	323	3.10	1024	20
21	.0282	.0285	.0288	12.50	12.77	13.04	407	2.46	812.3	21
22	.0250	.0253	.0256	15.82	16.20	16.59	516	1.94	640.1	22
23	.0224	.0226	.0228	19.95	20.31	20.67	647	1.55	510.8	23
24	.0199	.0201	.0203	25.17	25.67	26.19	818	1.22	404.0	24
25	.0177	.0179	.0181	31.66	32.37	33.10	1030	.970	320.4	25
26	.0157	.0159	.0161	40.01	41.02	42.07	1310	.765	252.8	26
27	.0141	.0142	.0143	50.72	51.43	52.17	1640	.610	201.6	27
28	.0125	.0126	.0127	64.30	65.33	66.37	2080	.481	158.8	28
29	.0112	.0113	.0114	79.80	81.22	82.68	2590	.387	127.7	29
30	.0099	.0100	.0101	101.7	103.7	105.8	3300	.303	100.0	30
31	.0088	.0089	.0090	128.0	130.9	133.9	4170	.240	79.21	31
32	.0079	.0080	.0081	158.1	162.0	166.2	5160	.194	64.00	32
33	.0070	.0071	.0072	200.1	205.7	211.7	6550	.153	50.41	33
34	.0062	.0063	.0064	253.2	261.3	269.8	8320	.120	39.69	34
35	.0055	.0056	.0057	319.2	330.7	342.8	10500	.0949	31.36	35
36	.0049	.0050	.0051	398.7	414.8	431.9	13200	.0757	25.00	36
37	.0044	.0045	.0046	490.1	512.1	535.7	16300	.0613	20.25	37
38	.0039	.0040	.0041	617.0	648.2	681.9	20600	.0484	16.00	38
39	.0034	.0035	.0036	800.2	846.6	897.1	27000	.0371	12.25	39
40	.0030	.0031	.0032	1013	1079	1152	34400	.0291	9.61	40
41	.0027	.0028	.0029	1233	1323	1423	42100	.0237	7.84	41
42	.0024	.0025	.0026	1534	1659	1801	52900	.0189	6.25	42
43	.0021	.0022	.0023	1960	2143	2352	68300	.0147	4.84	43
44	.0019	.0020	.0021	2352	2593	2873	82600	.0121	4.00	44

*Minimum and maximum dimensions are based on tolerances specified by ASTM Standard B3
** Values are based on a resistivity of 10.371 ohm per circular mil/ft at 20°C. (100% IACS conductivity). Minimum resistance values are based on maximum bare diameter. Maximum resistanc values are based on minimum bare diameter. In all cases, magnet wire will be furnished to dimensional standards. Resistance values serve as a guide only.