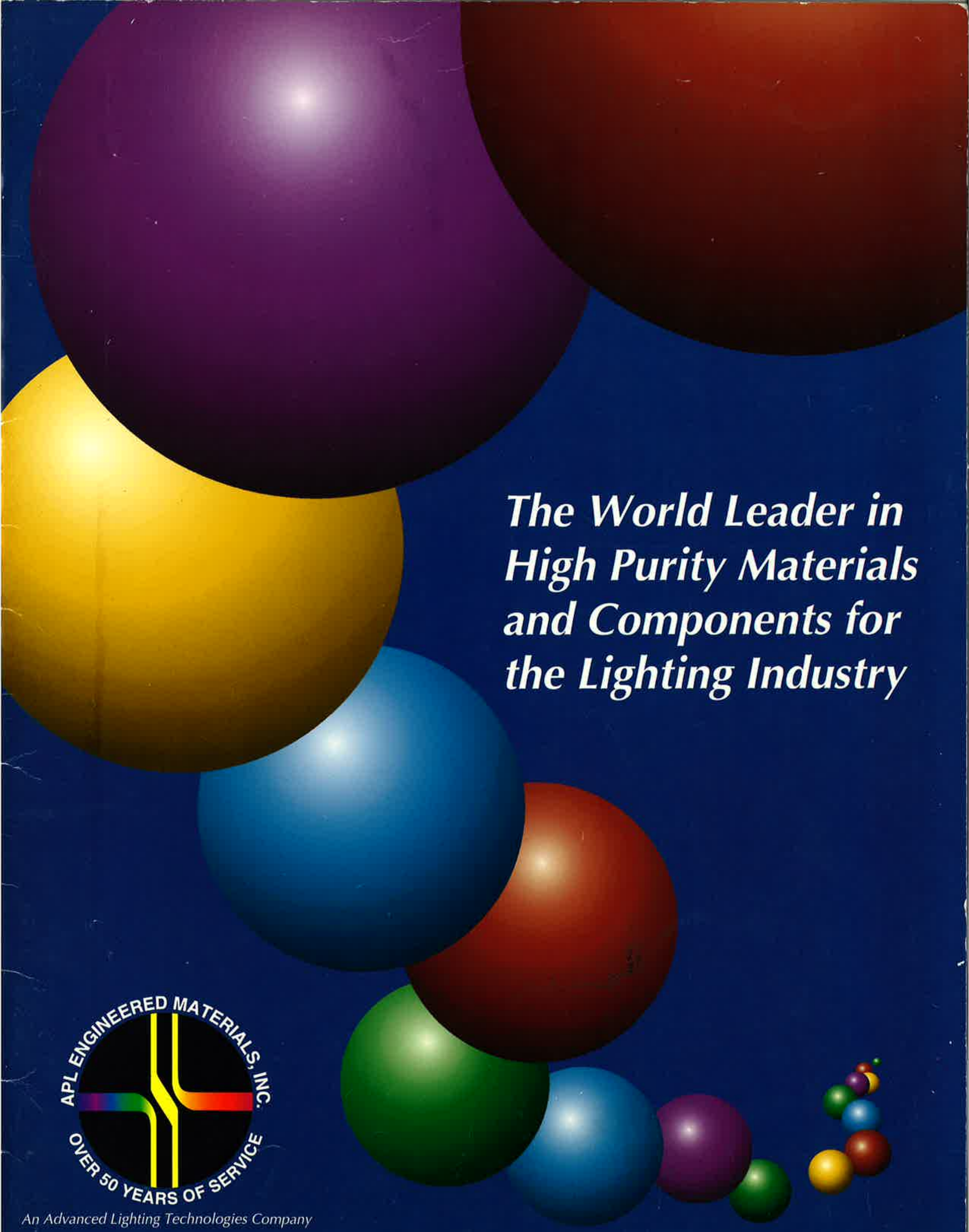
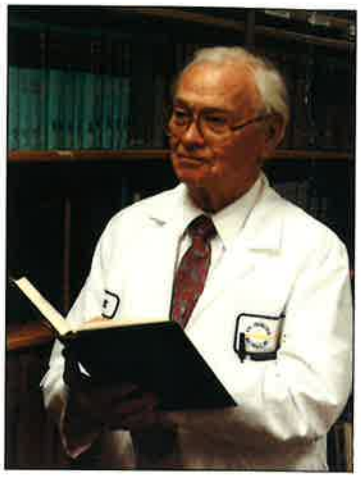


The World Leader in High Purity Materials and Components for the Lighting Industry

APL ENGINEERED MATERIALS, INC.
OVER 50 YEARS OF SERVICE

An Advanced Lighting Technologies Company

APL ENGINEERED MATERIALS WORLD LEADER IN ULTRA-PURE MATERIALS FOR LAMP APPLICATIONS



Dr. Scott Anderson

On August 7, 1944, Dr. Scott Anderson established the Anderson Physical Laboratory to perform sponsored experimental research in molecular physics. In the late 1950's, APL perfected several methods for purifying alkali metal halides which far exceeded all commercially available materials. These very pure materials found use in crystal growth, molten salt electrochemistry, and in color center research. In the following decade, APL pioneered the development of high-purity anhydrous iodides of precise sizes for the discharge lighting industry. These spheres dramatically improved metal halide lamp performance and made possible the development of high-speed dosing and manufacturing equipment. In 1971, these concepts were extended to include sodium-mercury amalgam spheres for high pressure sodium lamps and have recently been applied to zinc-mercury amalgam spheres for fluorescent lamps.

Jim Schoolenberg

In the early days of contract research at Anderson Physical Laboratory, working closely with the customer was essential. Today, this practice is continued as we strive to build a partnering relationship with each customer. The willingness of our customers to make APL part of their development effort enables us to make a contribution to the improvement of existing lighting products and to the creation of new ones.

The operation of our business is centered around the principles of Total Quality Management (TQM) with the goal of instilling an attitude of continuous improvement throughout the organization. Furthermore, the challenges raised by our customers have served to stimulate APL's dedicated employees as they search for novel solutions to proprietary problems. It is this commitment to excellence and our customer focus which will guarantee that APL's customers will receive the highest quality products and services at competitive prices.

APL Engineered Materials, Inc. reaffirms its tradition of serving our customers through working partnerships, but in the years ahead, our engineers and scientists will be taking a proactive stance as we strive to make significant contributions to the enhancement and growth of metal halide technology.

Jim Schoolenberg

Jim Schoolenberg
President & Chief Executive Officer

APL ENGINEERED MATERIALS, INC.
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Mission Statement:

We dedicate ourselves to being the premier supplier of metal halides, amalgams, metals, materials and other components used in the lighting industry, uniquely configured to meet specific customer requirements, with the greatest possible customer value.

APL's 30,000 square foot facility is located on a 30 acre parcel of land in Urbana, Illinois.

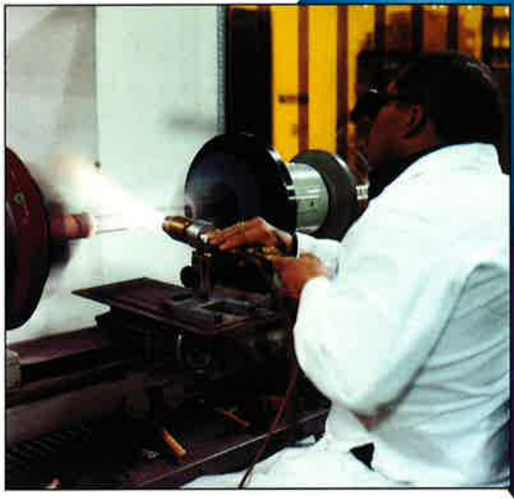
MATERIALS FOR METAL HALIDE LAMPS

When metal halides are excited in the arc tube of metal halide lamps, they emit visible and ultraviolet light. Optimum performance and maximum lifetime of metal halide lamps is achieved by using ultra-dry, high-purity materials of accurate mass and composition. APL Engineered Materials is recognized as the world's leading manufacturer of precisely-sized metal halides, metal halide mixtures and metal pieces for discharge lighting applications.

Ultra-pure and Ultra-dry

Materials with extremely low levels of water, hydroxide and anionic impurities are required for discharge lamp applications. APL's materials meet or exceed these requirements. Low levels of trace impurities are assured through rigorous purification processes and are certified by state-of-the-art chemical and spectroscopic analyses.

Argon-filled dry boxes maintain low parts-per-million levels of water and oxygen during the handling, sizing and ampouling of all metal halide lamp materials.



High-purity fused silca and borosilicate glassware is custom-fabricated to meet the demands of high temperature synthesis and purification of lamp materials.

Uniform Size and Composition

Most single component metal halides are available as spherical particles of precise mass or diameter. Multicomponent metal halide spheres of precise chemical composition and size can also be prepared. These precision engineered materials have low surface area, are free flowing and can be dosed with APL's high speed dispensing systems. APL also offers a wide variety of precision metal pieces that are useful in controlling metal-halogen arc tube chemistry and are a source of metal for *in situ* metal halide synthesis.

APL specializes in the manufacture of novel metal halide lamp materials and allows the discharge lamp designer freedom to choose materials with optimum spectral and performance characteristics. APL Engineered Materials stands ready to accept new challenges in materials for metal halide lamp research, development and production.

APL ENGINEERED MATERIALS, INC.
OVER 50 YEARS OF SERVICE

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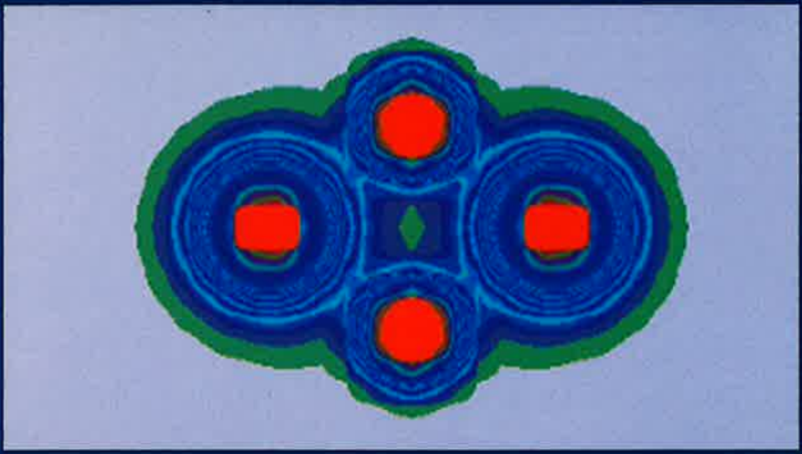
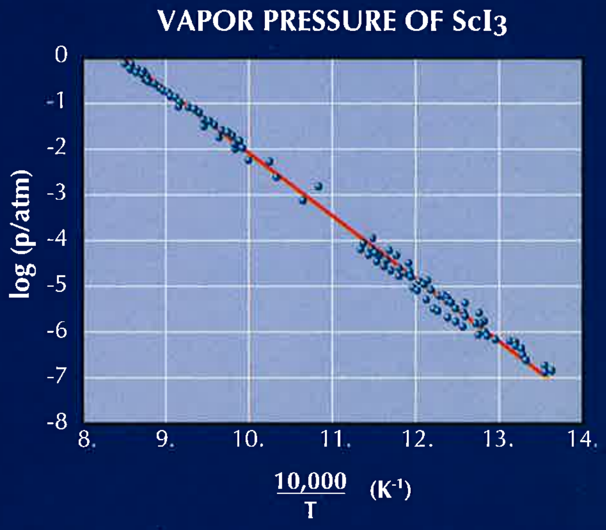
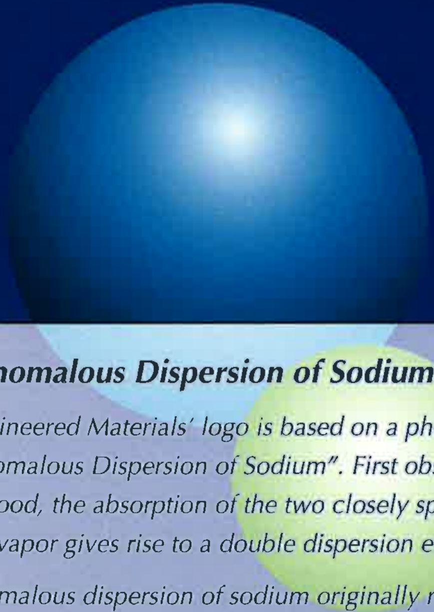


Electron density map of gaseous Na_2I_2.
(Image courtesy of ChemViz group at the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign).



Scandium iodide plays a central role in metal halide lamp technology. The experimental vapor pressure of scandium iodide (ScI_3) is shown here as a plot of the logarithm of pressure versus inverse absolute temperature.

The vapor phase chemistry of metal halides determines the number of atoms available to emit light within a metal halide arc tube. On a molecular level, monomeric gas phase species such as NaI, LiI and ScI_3, dimeric species such as Na_2I_2 and Li_2I_2, and complexes such as $NaScI_4$ and $CsDyI_4$ may all exist in the gas phase as vapors. Dimers and complexes are significant to the lamp designer since their higher vapor pressures increase the number of atoms in the arc and can lead to enhanced light output.



The Anomalous Dispersion of Sodium

APL Engineered Materials' logo is based on a phenomenon called the "Anomalous Dispersion of Sodium". First observed in 1904 by R.W. Wood, the absorption of the two closely spaced d-lines of sodium vapor gives rise to a double dispersion effect.

The anomalous dispersion of sodium originally represented APL's work in optical and spectroscopic research. It is significant today as a symbol of the central role of sodium radiation in metal halide and high pressure sodium lamp technology.

MATERIALS FOR METAL HALIDE LAMPS

Material	Symbol	Form	Standard Sizes	Special Order Sizes	Purity, %
Aluminum bromide	$AlBr_3$	Powder	-20 mesh	0.1 - 1.0 mg	99.999
Aluminum iodide	AlI_3	Spheres	-20 mesh, 0.5 mg, powder	0.1 - 3.0 mg	99.999
Antimony	Sb	Spheres		0.1 - 5.0 mg	99.999
Antimony (III) bromide	$SbBr_3$	Powder	-20 mesh	0.1 - 1.0 mg	99.999
Antimony (III) iodide	SbI_3	Spheres	-20 mesh, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Arsenic (III) iodide	AsI_3	Powder	-20 mesh		99.999
Barium bromide	$BaBr_2$	Spheres	-20 mesh	0.1 - 3.0 mg	99.999
Barium iodide	BaI_2	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 3.0 mg	99.999
Bismuth	Bi	Spheres	-20 mesh	0.1 - 3.0 mg	99.999
Bismuth (III) iodide	BiI_3	Spheres	-20 mesh, 0.5, 1.0, 2.0 mg	0.05 - 3.0 mg	99.999
Cadmium	Cd	Spheres	-20 mesh, 1.0 mg	0.1 - 5.0 mg	99.999
Cadmium bromide	$CdBr_2$	Spheres	-20 mesh, 0.5 mg	0.1 - 3.0 mg	99.999
Cadmium iodide	CdI_2	Spheres	-20 mesh, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Calcium bromide	$CaBr_2$	Spheres	-20 mesh	0.1 - 3.0 mg	99.995
Calcium iodide	CaI_2	Spheres	-20 mesh, 0.5 mg	0.1 - 3.0 mg	99.995
Cerium	Ce	Pieces		0.1 - 2.0 mg	99.9
Cerium (III) bromide	$CeBr_3$	Spheres	0.5 mg	0.1 - 2.0 mg	99.9
Cerium (III) iodide	CeI_3	Spheres	0.5 mg	0.1 - 2.0 mg	99.9
Cesium bromide	CsBr	Spheres	-20 mesh, 1.0 mg	0.05 - 3.0 mg	99.999
Cesium iodide	CsI	Spheres	-20 mesh, 0.1, 0.2, 0.5, 1.0, 2.0 mg	0.1 - 3.0 mg	99.999
Cobalt	Co	Pieces	0.25, 0.5, 1.0 mg	0.1 - 2.0 mg	99.996
Cobalt (II) bromide	$CoBr_2$	Spheres	-20 mesh, 0.2 mg	0.2 - 3.0 mg	99.998
Cobalt (II) iodide	CoI_2	Spheres	-20 mesh, 0.2, 0.5, 1.0 mg	0.2 - 3.0 mg	99.998
Dysprosium	Dy	Pieces	0.2, 0.5 mg	0.1 - 2.0 mg	99.9
Dysprosium (III) bromide	$DyBr_3$	Powder	0.5, 1.0 mg	0.1 - 2.0 mg	99.99
Dysprosium (III) iodide	DyI_3	Flakes			99.95
Erbium	Er	Pieces		0.1 - 2.0 mg	99.9
Erbium (III) bromide	$ErBr_3$	Powder		0.1 - 2.0 mg	99.99
Erbium (III) iodide	ErI_3	Powder			99.9
Europium	Eu	Pieces		0.1 - 1.0 mg	99.9
Europium (II) bromide	$EuBr_2$	Powder	-20 mesh		99.99
Europium (II) iodide	EuI_2	Powder	-20 mesh		99.9
Gadolinium	Gd	Pieces		0.1 - 2.0 mg	99.9
Gadolinium (III) bromide	$GdBr_3$	Powder	-20 mesh		99.99
Gadolinium (III) iodide	GdI_3	Powder	-20 mesh		99.99
Gallium	Ga	Spheres	1.0 mg	0.1 - 1.0 mg	99.999
Gallium (III) bromide	$GaBr_3$	Spheres	-20 mesh		99.999
Gallium (III) iodide	GaI_3	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 3.0 mg	99.999
Hafnium	Hf	Pieces		0.1 - 3.0 mg	99.5
Hafnium (IV) bromide	$HfBr_4$	Powder	-60 mesh		98.5
Hafnium (IV) iodide	HfI_4	Powder	-60 mesh		98.5
Holmium	Ho	Pieces	0.1, 0.25, 0.5 mg	0.1 - 2.0 mg	99.9

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* *Vapor pressure is less than 10^{-8} atm at 1000 K* ° *Calculated from x-ray diffraction data.*

† *Total vapor pressure above liquid except as noted by (s). $\log_{10}(p/atm) = A/T+B$ (T in Kelvin).* *(s) Total vapor pressure above solid.* *(A catalog of metal halide vapor pressures is available from APL on request.)*

Color	Molecular Weight	Density g/cm^3	Melting Point °C	Boiling Point °C	Vapor Pressure†		CAS Registry No.
					A	B	
White	266.69	3.20	97.8	256	-2,666	5.0380	7727-15-3
White	407.69	3.98	191	382	-3,768	5.7583	7784-23-8
Silver Metallic	121.76	6.70	630.6	1624	-6,553	3.4536	7440-36-0
White	361.47	4.15	96	288	-3,054	5.5037	7789-61-9
Dark Red/Violet	502.47	4.92	171	401	-3,396	5.0031	7790-44-5
Burnt Orange	455.63	4.39	146		-3,333	5.2318	7784-45-4
White	297.14	4.78	857	1849	-14,670	6.912	10553-31-8
White	391.14	5.15	711	2027	-11,710	5.093	13718-50-8
Silver White	208.98	9.81	271	1564	-9,685	5.2858	7440-69-9
Black	589.69	5.78	413	542	-4,310	5.289	7787-64-6
Silver White	112.41	8.65	321.1	767	-5,317	5.1181	7440-43-9
White	272.22	5.19	570	863	-5,951	5.2711	7789-42-6
White	366.22	5.67	388	796			7790-80-9
White	199.89	3.35	730	1815	-12,380	5.923	7789-41-5
White	293.89	3.96	784		-11,736	6.2768	10102-68-8
Gray Metallic	140.12	6.77	798	3443	*	*	7440-45-1
White	379.83	5.18	732		-13,592	8.0152$^{(s)}$	14457-87-5
Yellow	520.83	5.68$^{\diamond}$	760		-14,848	10.2544$^{(s)}$	7790-87-6
White	212.81	4.44	636	1300	-8,279	5.3132	7787-69-1
White	259.81	4.51	621	1280	-7,472	4.7439	7789-17-5
Silver Gray	58.93	8.90	1495	3100	*	*	7440-48-4
Emerald Green	218.74	4.91	678	decomposes	-10,362	8.6952$^{(s)}$	7789-43-7
Black	312.74	5.68	515	decomposes	-7,110	5.6818$^{(s)}$	15238-00-3
Silver Metallic	162.50	8.55	1412	2567	*	*	7429-91-6
Pale Yellow/White	402.21	4.78	881		-10,834	6.4519$^{(s)}$	14456-48-5
Dark Yellow	543.21	5.35$^{\diamond}$	983		-13,631	9.3582$^{(s)}$	15474-63-2
Silver Metallic	167.26	9.07	1529	2868	*	*	7440-52-0
Violet Rose	406.97	4.93	950		-11,395	7.0474$^{(s)}$	13536-73-7
Pale Violet Rose	547.97	5.46$^{\diamond}$	1014		-15,122	10.90$^{(s)}$	13813-42-8
Steel Gray	151.97	5.24	822	1529	-7,905	4.3874	7440-53-1
White	311.77	5.44$^{\diamond}$	683		-12,730	5.03	13780-48-8
Pale Yellow	405.77	5.50	580		-13,703	6.957	22015-35-6
Silver Metallic	157.25	7.90	1313	3273	*	*	7440-54-2
White	396.96	4.57	785	1490	-10,084	5.6814$^{(s)}$	13818-75-2
Pale Yellow/White	537.96	5.23$^{\diamond}$	931		-16,009	11.55$^{(s)}$	13572-98-0
Silver Luster	69.72	5.90	29.8	2403	-12,936	4.8433	7440-55-3
White	309.44	3.69	122.5	279	-3,121	5.6566	13450-88-9
Yellow	450.44	4.15	214	349	-3,669	5.9418	13450-91-4
White Metallic	178.49	13.32	2233	4603	*	*	7440-58-6
White	498.11		424.5	322 sublimes	-5,257	8.816$^{(s)}$	13777-22-5
Yellow Orange	686.11	5.60$^{\diamond}$	477	400 sublimes	-5,929	8.8618$^{(s)}$	13777-23-6
Gray Metallic	164.93	8.80	1474	2700	*	*	7440-60-0

MATERIALS FOR METAL HALIDE LAMPS

Material	Symbol	Form	Standard Sizes	Special Order Sizes	Purity, %
Holmium (III) bromide	$HoBr_3$	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 1.0 mg	99.99
Holmium (III) iodide	HoI_3	Powder	-20 mesh		99.99
Indium	In	Spheres	0.1, 0.5, 1.0 mg	0.05 - 1.0 mg	99.999
Indium (I) bromide	InBr	Spheres	-20 mesh, 0.5 mg	0.05 - 3.0 mg	99.999
Indium (I) iodide	InI	Spheres	-20 mesh, 0.1, 0.25, 0.5 mg	0.05 - 3.0 mg	99.999
Indium (III) iodide	InI_3	Spheres	-20 mesh, 0.2, 0.5 mg	0.1 - 1.0 mg	99.999
Iodine	I_2	Spheres	1.0 mg	0.1 - 2.0 mg	99.999
Iron	Fe	Pieces	0.1, 0.5, 1.0 mg	0.1 - 2.0 mg	99.995
Iron (II) bromide	$FeBr_2$	Spheres	-20 mesh, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Iron (II) iodide	FeI_2	Spheres	-20 mesh, 0.2, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Lanthanum	La	Pieces		0.1 - 1.0 mg	99.9
Lanthanum (III) bromide	$LaBr_3$	Spheres	-20 mesh	0.1 - 1.0 mg	99.99
Lanthanum (III) iodide	LaI_3	Powder	-20 mesh		99.9
Lead	Pb	Spheres	-20 mesh, 1.0 mg	0.1 - 2.0 mg	99.999
Lead (II) bromide	$PbBr_2$	Spheres	-20 mesh, 0.5 mg	0.05 - 3.0 mg	99.999
Lead (II) iodide	PbI_2	Spheres	-20 mesh, 0.25, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Lithium bromide	LiBr	Spheres	-20 mesh, 0.1, 0.2, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Lithium iodide	LiI	Sph/Pwd	-20 mesh, 0.1, 0.25, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Lutetium	Lu	Pieces		0.1 - 1.0 mg	99.9
Lutetium (III) bromide	$LuBr_3$	Sph/Pwd	-20 mesh powder	0.1 - 1.0 mg	99.99
Lutetium (III) iodide	LuI_3	Powder	-20 mesh powder		99.9
Magnesium bromide	$MgBr_2$	Spheres	-20 mesh	0.1 - 3.0 mg	99.99
Magnesium iodide	MgI_2	Spheres	-20 mesh, 0.5 mg	0.1 - 3.0 mg	99.999
Manganese (II) iodide	MnI_2	Powder	-20 mesh		99.99
Mercury (II) bromide	$HgBr_2$	Spheres	-20 mesh, 0.1, 0.25, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Mercury (II) chloride	$HgCl_2$	Spheres	-20 mesh, 0.1 mg	0.05 - 3.0 mg	99.999
Mercury (II) iodide	HgI_2	Spheres	-20 mesh, 0.1, 0.5, 1.0 mg	0.05-3.0 mg, 5-10 mg	99.999
Neodymium	Nd	Pieces		0.1 - 1.0 mg	99.9
Neodymium (III) bromide	$NdBr_3$	Spheres	-20 mesh	0.1 - 2.0 mg	99.99
Neodymium (III) iodide	NdI_3	Powder	-20 mesh	1.0 mg	99.99
Nickel	Ni	Pieces		0.1 - 1.0 mg	99.94
Nickel (II) iodide	NiI_2	Powder			99.995
Potassium iodide	KI	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 3.0 mg	99.999
Praseodymium	Pr	Pieces		0.1 - 1.0 mg	99.9
Praseodymium (III)bromide	$PrBr_3$	Spheres	-20 mesh	0.1 - 2.0 mg	99.9
Praseodymium (III) iodide	PrI_3	Powder	-20 mesh		99.9
Rubidium bromide	RbBr	Spheres	-20 mesh	0.1 - 3.0 mg	99.99
Rubidium iodide	RbI	Spheres	-20 mesh	0.1 - 3.0 mg	99.99
Samarium	Sm	Pieces		0.1 - 1.0 mg	99.9
Samarium (II) iodide	SmI_2	Powder			99.9
Scandium	Sc	Pieces	0.1, 0.25, 0.5, 1.0, 2.0 mg	0.05 - 3.0 mg	99.9
Scandium (III) bromide	$ScBr_3$	Powder			99.99

** Vapor pressure is less than 10^{-8} atm at 1000 K* *◊ Calculated from x-ray diffraction data.*

† Total vapor pressure above liquid except as noted by (s). $\log_{10}$ (p/atm) = A/T+B (T in Kelvin). *(s) Total vapor pressure above solid.* *(A catalog of metal halide vapor pressures is available from APL on request.)*

Color	Molecular Weight	Density g/cm³	Melting Point °C	Boiling Point °C	Vapor Pressure†		CAS Registry No.
					A	B	
Light Pink	404.64	4.86	919		-11,152	6.7445$^{(s)}$	13825-76-8
Light Yellow	545.64	5.40$^{\Diamond}$	1014		-14,755	10.3396$^{(s)}$	13813-41-7
Silver White	114.82	7.31	156.6	2080	-12,242	5.2214	7440-74-6
Orange Red	194.72	4.96	285	677	-5,017	5.3014	14280-53-6
Violet	241.72	5.31	359	726	-5,384	5.3869	13966-94-4
Yellow Orange	495.53	4.69	207	500	-4,611	5.966	13510-35-5
Violet Black	126.90	4.94	113.6	185	-2,238	4.888	7553-56-2
Silver Metallic	55.85	7.87	1538	2861	*	*	7439-89-6
Bronze	215.66	4.64	684	decomposes	-6,912	5.569	7789-46-0
Dark Violet	309.66	5.32	594	879	-6,922	6.0082	7783-86-0
White Metallic	138.91	6.15	918	3464	*	*	7439-91-0
White	378.62	5.07	788		-15,358	9.3938$^{(s)}$	13536-79-3
Pale Yellow Green	519.62	5.63	778		-15,784	11.091$^{(s)}$	13813-22-4
Silver Metallic	207.2	11.34	327.5	1751	-9,525	4.7192	7439-92-1
White	367.01	6.66	373		-7,152	6.185	10031-22-8
Orange Rust	461.01	6.2	402	decomposes	-6,115	5.3842	10101-63-0
White	86.85	3.46	550	1265	-8,805	5.7549	7550-35-8
White	133.85	4.08	468	1180	-7,734	5.2955	10377-51-2
Silver Gray	174.97	9.84	1663	3402	*	*	7439-94-3
White	414.68	5.17	1025		-11,508	7.4005$^{(s)}$	14456-53-2
Pale Beige	555.68	5.64$^{\Diamond}$	1050	1200	-10,011	6.750$^{(s)}$	13813-45-1
White	184.11	3.72	711		-8,104	5.4341	7789-48-2
White	278.11	4.43	650		-11,136	10.4667$^{(s)}$	10377-58-9
Pale Violet	308.75	5.01	636	1062	-7,675	5.7487	7790-33-2
White	360.40	6.05	238	318	-3,122	5.2647	7789-47-1
White	271.50	5.44	280	303	-3,095	5.3636	7487-94-7
Dark Red	454.40	6.36	257	351	-3,271	5.2223	7774-29-0
Silver White	144.24	7.01	1021	3074	*	*	7440-00-8
Blue Green	383.95	5.35	682		-13,565	8.3376$^{(s)}$	13536-80-6
Jade Green	524.95	5.85$^{\Diamond}$	787		-14,519	10.0758$^{(s)}$	13813-24-6
Silver Metallic	58.69	8.91	1455	2920	*	*	7440-02-0
Black	312.50	5.83	797	decomposes	-8,807	8.520$^{(s)}$	13462-90-3
White	166.00	3.13	723	1330	-7,755	4.8596	7681-11-0
Silver Metallic	140.91	6.77	931	3520	*	*	7440-10-0
Pale Green	380.62	5.26	693		-13,631	8.2405$^{(s)}$	13536-53-3
Olive Green	521.62	5.77$^{\Diamond}$	738		-15,352	10.9364$^{(s)}$	13813-23-5
White	165.37	3.35	693	1340	-8,619	5.3692	7789-39-1
White	212.37	3.55	646	1300	-8,010	5.0953	7790-29-6
Silver Metallic	150.36	7.52	1074	1794	-9,141	4.4360	7440-19-9
Black	404.17	5.47	527		-13,367	6.92	32248-43-4
Silver Gray Metallic	44.96	2.99	1541	2836	*	*	7440-20-2
White	284.67	3.91	970		-15,169	12.6574$^{(s)}$	13465-59-3

MATERIALS FOR METAL HALIDE LAMPS

Material	Symbol	Form	Standard Sizes	Special Order Sizes	Purity, %
Scandium (III) iodide	ScI_3	Powder			99.999
Scandium (III) oxide	Sc_2O_3	Powder	-325 mesh		99.99
Silicon (IV) iodide	SiI_4	Spheres	-20 mesh		99.999
Silver (I) iodide	AgI	Spheres	-20 mesh, 0.5 mg	0.1 - 3.0 mg	99.999
Sodium bromide	NaBr	Spheres	-20 mesh, 0.5 mg	0.05 - 3.0 mg	99.999
Sodium iodide	NaI	Spheres	-20 mesh, 0.1,0.25, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Strontium bromide	$SrBr_2$	Spheres	-20 mesh, 0.5 mg	0.1 - 3.0 mg	99.999
Strontium iodide	SrI_2	Spheres	-20 mesh	0.1 - 3.0 mg	99.995
Tellurium (IV) bromide	$TeBr_4$	Powder	-20 mesh		99.995
Tellurium (IV) iodide	TeI_4	Powder	-20 mesh		99.9
Terbium	Tb	Pieces		0.1 - 2.0 mg	99.95
Terbium (III) bromide	$TbBr_3$	Powder	-20 mesh	0.1 - 1.0 mg	99.95
Terbium (III) iodide	TbI_3	Powder			99.99
Thallium (I) bromide	TlBr	Spheres	-20 mesh, 0.2 mg	0.05 - 3.0 mg	99.999
Thallium (I) chloride	TlCl	Spheres	-20 mesh	0.1 - 3.0 mg	99.99
Thallium (I) iodide	TlI	Spheres	-20 mesh, 0.1, 0.2, 0.5, 1.0 mg	0.05-3 mg, 5-10 mg	99.999
Thorium (IV) bromide	$ThBr_4$	Spheres	-20 mesh	0.1 - 1.0 mg	99.95
Thorium (IV) iodide	ThI_4	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 3.0 mg	99.99
Thorium (IV) oxide	ThO_2	Powder	-325 mesh		99.99
Thulium	Tm	Pieces	0.25, 0.5 mg	0.1 - 2.0 mg	99.9
Thulium (III) bromide	$TmBr_3$	Powder		1.0 mg	99.99
Thulium (III) iodide	TmI_3	Powder			99.95
Tin	Sn	Pieces	0.1, 0.5, 1.0 mg	0.1 - 2.0 mg	99.999
Tin (II) bromide	$SnBr_2$	Spheres	-20 mesh, 0.5, 1.0 mg	0.1 - 2.0 mg	99.999
Tin (II) chloride	$SnCl_2$	Spheres	-20 mesh, 0.5 mg	0.1 - 1.0 mg	99.999
Tin (II) iodide	SnI_2	Spheres	-20 mesh, 0.1, 0.2, 0.5, 1.0 mg	0.05 - 3.0 mg	99.999
Tin (IV) iodide	SnI_4	Powder	-60 mesh		99.999
Titanium (IV) bromide	$TiBr_4$	Powder			99.99
Titanium (IV) iodide	TiI_4	Powder			99.99
Ytterbium	Yb	Pieces		0.1 - 1.0 mg	99.9
Ytterbium (III) bromide	$YbBr_3$	Sph/Pwd	-20 mesh	1.0 mg	99.99
Ytterbium (II) iodide	YbI_2	Powder		0.1 - 1.0 mg	99.95
Yttrium	Y	Pieces		0.1 - 1.0 mg	99.9
Yttrium (III) bromide	YBr_3	Sph/Pwd	-20 mesh	0.1 - 1.0 mg	99.99
Yttrium (III) iodide	YI_3	Powder			99.95
Zinc	Zn	Spheres	-20 mesh, 1.0 mg	0.1 - 2.0 mg	99.995
Zinc bromide	$ZnBr_2$	Spheres	-20 mesh, 0.5 mg	0.05 - 3.0 mg	99.999
Zinc iodide	ZnI_2	Spheres	-20 mesh, 0.1, 0.2, 0.5 mg	0.05 - 3.0 mg	99.999
Zirconium	Zr	Pieces		0.1 - 2.0 mg	99.99
Zirconium (IV) iodide	ZrI_4	Powder			99.95

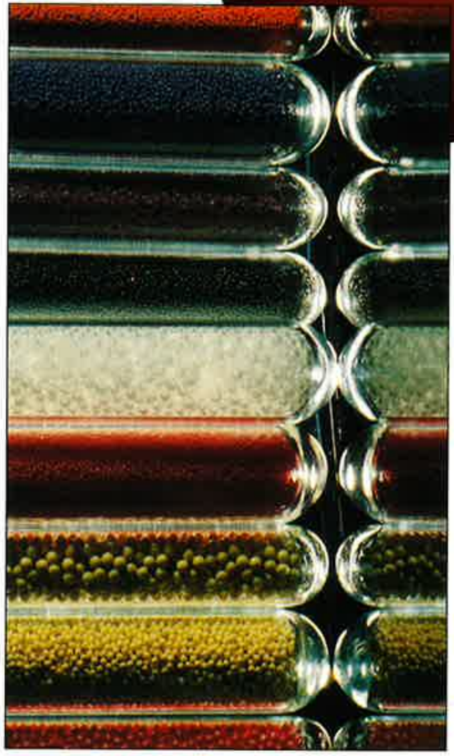
** Vapor pressure is less than 10^{-8} atm at 1000 K* *◊ Calculated from x-ray diffraction data.*

† Total vapor pressure above liquid except as noted by (s). $\log_{10}$ (p/atm) = A/T+B (T in Kelvin). *(s) Total vapor pressure above solid.* *(A catalog of metal halide vapor pressures is available from APL on request.)*

Color	Molecular Weight	Density g/cm³	Melting Point °C	Boiling Point °C	Vapor Pressure † A	B	CAS Registry No.
Pale Yellow	425.67	4.70◊	953	912 sublimes	-13,629	11.5202$^{(s)}$	14474-33-0
White	137.91	3.86	2403		*	*	12060-08-1
White	535.70	4.20	121	288	-2,824	4.9342	13465-84-4
Pale Yellow	234.77	5.68	557	1506			7783-96-2
White	102.89	3.20	747	1390	-8,552	5.1498	7647-15-6
White	149.89	3.67	662	1304	-8,046	5.0844	7681-82-5
White	247.43	4.22	657	2045	-12,710	5.481	10476-81-0
White	341.43	4.55	538	1773	-12,410	6.066	10476-86-5
Orange	447.22	4.31	363 under Br_2	414 under Br_2	-5,978	8.55$^{(s)}$	10031-27-3
Gray Black	635.22	5.05	280		-4,408	7.6557$^{(s)}$	7790-48-9
Silver Gray Metallic	158.93	8.23	1356	3230	*	*	7440-27-9
White	398.64	4.67	827		-10,357	6.0325$^{(s)}$	14456-47-4
White	539.64	5.26◊	955		-14,021	9.70$^{(s)}$	13813-40-6
Light Yellow	284.29	7.56	480	815	-5,548	5.0876	7789-40-4
White	239.84	7.00	430		-5,596	5.1419	7791-12-0
Yellow	331.29	7.10	442	823	-5,749	5.2433	7790-30-9
White	551.65	5.67	679	857	-7,566	6.6984	13453-49-1
Yellow	739.65	6.0	566	839	-6,918	6.2350	7790-49-0
White	264.04	9.86	3390	4400	-35,520	8.26$^{(s)}$	1314-20-1
Silver Metallic	168.93	9.32	1545	1950	-10,106	4.5464	7440-30-4
Cream White	408.65	5.02	952		-11,187	6.9839$^{(s)}$	14456-51-0
Yellow	549.65	5.53◊	1030		-14,209	10.1562$^{(s)}$	13813-43-9
Silver White	118.71	7.27	231.9	2623	*	*	7440-31-5
Red Yellow	278.52	5.12	216	620	-5,403	5.9817	10031-24-0
White	189.62	3.95	246		-5,183	5.889	7772-99-8
Magenta	372.52	5.29	320	720	-5,464	5.5313	10294-70-9
Orange	626.33	4.56	145		-2,985	4.8050	7790-47-8
Orange Yellow	367.50	2.6	39	234	-2,570	5.1090	7789-68-6
Red Brown	555.50	4.3	150	377	-3,054	4.696	7720-83-4
Silver Metallic	173.04	6.90	819	1196	-6,884	4.6936	7440-64-4
Yellow/White	412.75	5.10	956	decomposes			13759-89-2
Gold Yellow	426.85	5.70	780	≈ 1300	-8,600	5.41	13469-98-2
Silver Gray Metallic	88.91	4.47	1522	3345	*	*	7440-65-5
White	328.62	3.95	904		-11,526	7.1119$^{(s)}$	13649-48-2
White	469.62	4.59◊	997		-11,706	6.66$^{(s)}$	13470-38-7
Blue White Metallic	65.39	7.14	419.5	907	-6,168	5.2300	7440-66-6
White	225.20	4.20	394	650	-6,193	6.6663	7699-45-8
White	319.20	4.74	446	> 700	-5,629	5.5959	10139-47-6
Gray White Metallic	91.22	6.51	1855	4200	*	*	7440-67-7
Orange	598.84	4.79◊	499^{6atm}	420 sublimes	-6,771	9.6828$^{(s)}$	13986-26-0

MULTICOMPONENT METAL HALIDE MIXTURES

The combination of two or more metal halide components allows the spectral output of a metal halide lamp to be tailored to specific applications. APL's unique capabilities in combining two or more components into a single sphere permit the lamp manufacturer to dose single spheres of uniform composition and mass, with negligible sphere-to-sphere or lamp-to-lamp variation. We welcome the opportunity to discuss the feasibility of manufacturing custom mixtures to your specifications.



Mixtures

High-purity multicomponent metal halide mixtures which melt at temperatures up to 950C can be formed into spherical pellets with narrow mass variation. Many high melting metal halides such as rare earth iodides can be supplied as a mixture with a lower melting component such as sodium iodide. APL welcomes the opportunity to help the lamp engineer develop the appropriate mixed pellet which can lead to greater manufacturing efficiency and to less lamp-to-lamp variation in spectral output and performance.

The materials below give an indication of the wide range of possible mixtures which can be supplied in the form of a single pellet:

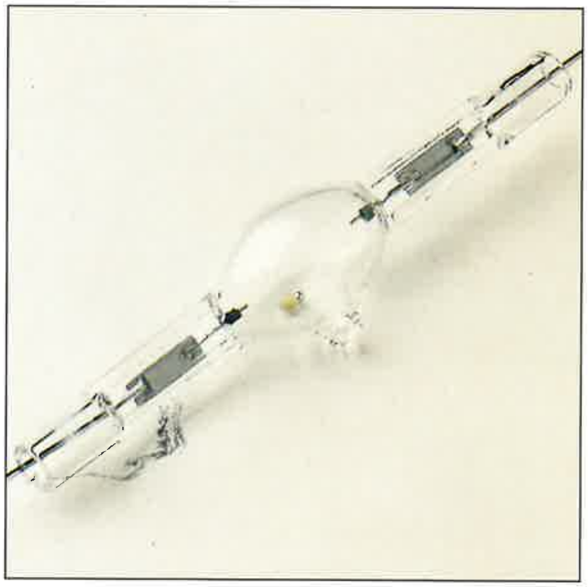
$\mathrm{NaI-ScI_3}$
$\mathrm{NaX - ScX_3}$
$\mathrm{NaX - ScX_3 - AX}$
$\mathrm{NaX - InX - TlX - AX}$
$\mathrm{LnX_3 - MX - AX}$
$\mathrm{SnX_2 - AX}$
$\mathrm{NaI - ScI_3 - AX}$
$\mathrm{NaI - InI - TlI}$
$\mathrm{HgI_2 - HgBr_2}$
$\mathrm{HgI_2 - AX}$
$\mathrm{FeX_2 - AX}$
$\mathrm{LnX_3 - MX}$

Ln = One or more of the Lanthanide Metals: Ce, Pr, Nd, Gd, Tb, Dy, Ho, Er, Tm, Lu

M = Li, Na, K, Rb, Cs

X = Br or I

AX = Other metal halides from pages 6-11. These may be combined to formulate custom multicomponent mixtures.



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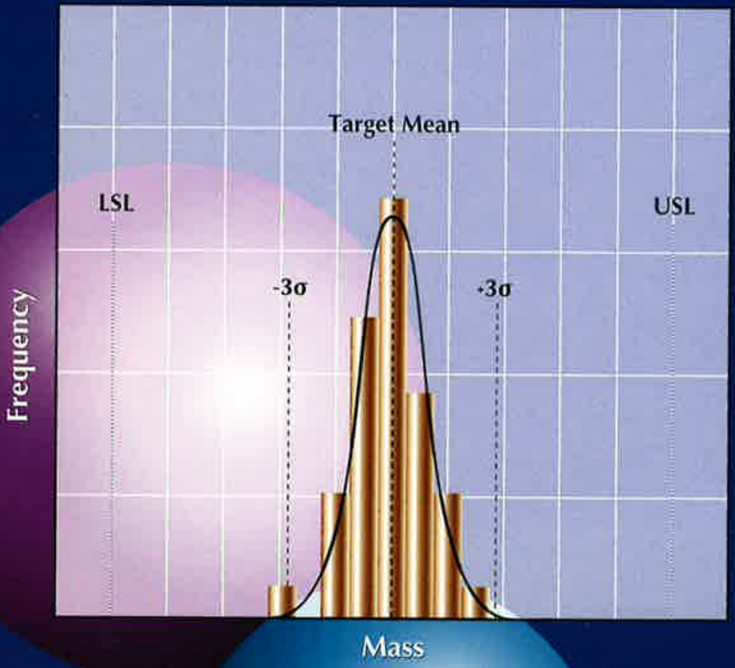
PRECISION METAL PIECES FOR METAL HALIDE LAMPS

In metal halide arc tubes, a precision metal piece allows the *in situ* synthesis of the appropriate metal halide. Besides the synthesis of a metal halide, a metal piece can also extend the lamp life and improve performance by ameliorating the problems of excess iodine and oxygen contamination.

Precision metal pieces generally have mass tolerances of 5% or better and are usually available in weights from approximately 0.1 mg to 2.0 mg, depending on the density of the material. Precision metal pieces are available in virtually all metals.

APL's high-purity distilled scandium metal.

Histogram of Precision Metal Pieces



Metals	Sizes Available/mg
Scandium	0.05 - 2.0
Yttrium	0.1 - 2.0
Lanthanum	0.1 - 2.0
Cerium	0.1 - 2.0
Praseodymium	0.1 - 2.0
Neodymium	0.1 - 2.0
Samarium	0.1 - 2.0
Europium	0.1 - 2.0
Gadolinium	0.1 - 2.0
Terbium	0.1 - 2.0
Dysprosium	0.1 - 2.0
Holmium	0.1 - 2.0
Erbium	0.1 - 2.0
Thulium	0.1 - 2.0
Ytterbium	0.1 - 2.0
Lutetium	0.1 - 2.0
Iron	0.1 - 2.0
Cobalt	0.1 - 2.0
Nickel	0.1 - 2.0
Hafnium	0.25 - 4.0
Zirconium	0.1 - 2.0
Silver	0.2 - 3.0
Zinc	0.1 - 2.0
Cadmium	0.1 - 2.0
Tin	0.1 - 2.0
Alloys	
Dy-Ho	0.1 - 2.0
Dy-Ho-Tm	0.1 - 2.0
Na-Sn	0.1 - 2.0

Proprietary alloy compositions can be prepared on request.

AMALGAMS FOR HIGH PRESSURE SODIUM LAMPS

Sodium-mercury amalgams are used in high-pressure sodium lamps to provide a pressure-broadened sodium emission spectrum. Mercury lowers the operating current and improves the color rendition of the lamp.

When handled alone both sodium and mercury are difficult to introduce into a standard arc tube. However, when combined into an amalgam sphere, they are free flowing and readily dispensed.

APL Engineered Materials produces a wide variety of sodium-mercury amalgam spheres with tight control of sphere mass and diameter. Spheres from approximately 3 weight percent sodium up to 25 weight percent sodium and from approximately 0.1 mg up to 6 mg in mass are available.

The same principles used to produce sodium-mercury amalgams are also applicable to other alkali-metal amalgams. Amalgams of cesium, rubidium, potassium and other metals which form a solid at room temperature can be considered. Challenge us with your special requirements.

Advantages of Sodium-Mercury Amalgam Spheres:

- *Precise doses of both sodium and mercury*
- *Wide ranges of compositions available*
- *Oxide-free spheres of highly-pure metals*
- *Free flowing*
- *Readily dosable using automated machinery*

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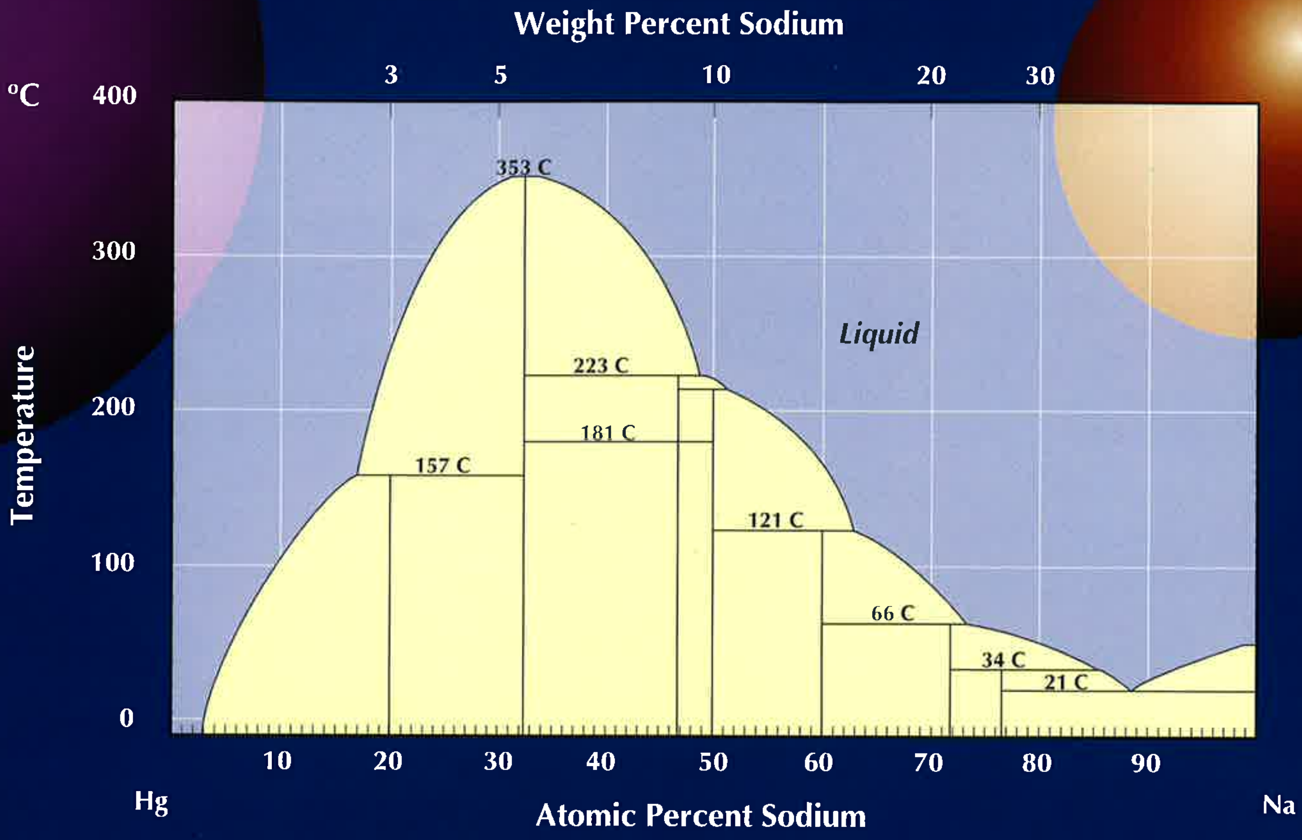
The Binary Mercury-Sodium Phase Diagram



A phase diagram is a roadmap of the various alloys that can be made from two metals. The mercury-sodium phase diagram shows a large number of intermetallic phases and a peritectic cascade from 353C to 21C that includes five invariant reactions. Most of the amalgams used in high pressure sodium lamps have compositions lying between 33 and 80 atomic percent sodium.

Alkali Metal Amalgams

Alkali Metal Amalgam	Composition Range (solid at 25°C)	Sphere Diameter Range	Sphere Mass Range
Na-Hg	3 - 30 wt % Na	0.2 - 1.5 mm	0.1 - 6 mg
K-Hg	3 - 16 wt % K	0.2 - 1.5 mm	0.5 - 6 mg
Rb-Hg	4 - 28 wt % Rb	0.2 - 1.5 mm	0.5 - 6 mg
Cs-Hg	10 - 40 wt % Cs	0.2 - 1.5 mm	0.5 - 6 mg

Other specialty metal compositions can be prepared on request.

FLUORESCENT LAMP MATERIALS

All fluorescent lamps contain mercury vapor which is excited by an electrical discharge. The resulting ultraviolet radiation is absorbed by a phosphor coating on the glass tube and converted into visible light.

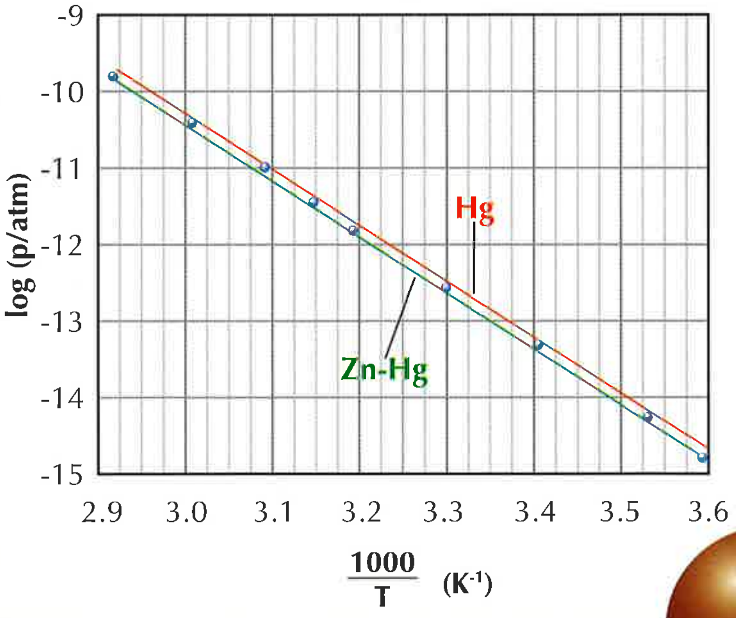
Zn-Hg

Solid zinc-mercury (Zn-Hg) amalgam spheres provide a means of dosing a precise amount of mercury as a solid, thereby avoiding the problems of poor reproducibility associated with liquid mercury dosing. Uniformly-sized Zn-Hg spheres can permit significant reductions in total mercury dose required to meet current and future environmental regulations.

Features:

- *Provides 95% of the vapor pressure of pure Hg*
- *Zn is inert in lamp*
- *Can be dosed with automated dispensers*
- *Free flowing solid spheres -- easier to handle than liquid Hg*
- *Coated material available for use up to 125 C*

Mercury Vapor Pressure above Zn-Hg Amalgam



Selection Guide for 50-50 Zn-Hg Spheres*

Mass	Diameter	Available Hg
4.0 mg	935 µm	1.8 mg
8.0 mg	1180 µm	3.6 mg
14.0 mg	1420 µm	6.3 mg
16.0 mg	1485 µm	7.1 mg

** Standard composition is 50 wt % Hg. Other compositions are available.*

Compact Fluorescent Lamp Amalgams

Amalgam	Composition (wt%)	Size Range
Bi-In-Hg	68 - 29 - 3	2.0 - 3.0 mm
Bi-Pb-Sn-Hg	45.5 - 33 - 19.5 - 3	2.0 - 3.0 mm

Auxiliary Amalgams

Indium-Coated Mesh	Mesh Size* mm	Available Indium mg /cm^2
3 - 50 mm continuous ribbon	2.03 x 1.27 to .79 x .56	1 - 5

** Strand width and sheet thickness can be specified.*

Compact Fluorescent Lamp Materials

APL also supplies amalgams made especially for compact fluorescent lamps. These amalgams generally contain Hg plus two or more metals such as Bi, In, Pb, and Sn. They are designed to regulate the vapor pressure of mercury at the high operating temperature of the lamp. These amalgams are available as spheres of precise diameter or weight, typically in the range of 2.0 to 3.0 mm. Custom compositions and sizes are readily prepared.

A custom indium-coated expanded metal mesh is manufactured for use as the "auxiliary" amalgam in certain types of compact and electrodeless lamps. This material is available as continuous ribbon on spools, with dimensions and coating thickness according to your specification.

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THERMIONIC EMISSION MATERIALS

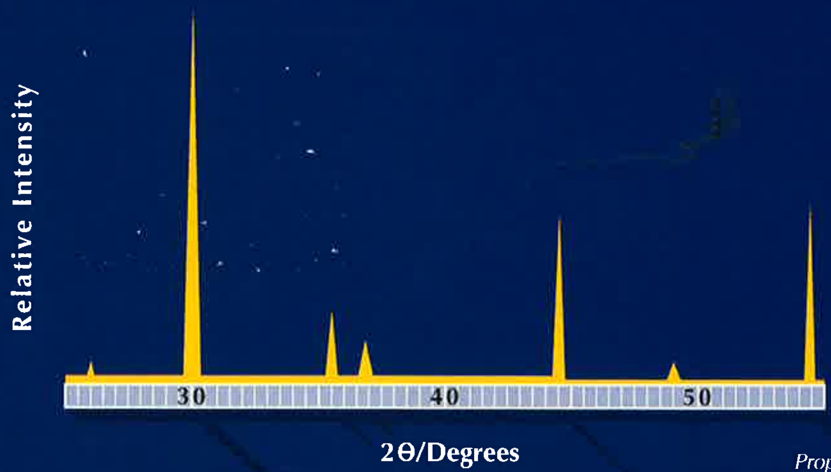
APL produces a wide range of thermionic emission materials for use in high pressure sodium lamps and other types of electron devices. These emission materials are supplied as fine powders after they have been reacted at high temperatures to create the desired phase(s). Tungstate, scandate, and aluminate emission materials are available prereacted and require no further processing before use. Proprietary formulations are also available as well as mixtures of thoria and yttria.

Phase purity is generally 99.5% or better as measured by x-ray diffraction. The chemical purity is approximately 99.9%.

Tungstates	Scandates	Aluminates	Thoria-Yttria Mixtures
Ba_2CaWO_6	$Ba_3Sc_4O_9$	$5BaO - 3CaO - 2Al_2O_3$	85% ThO_2 - 15% Y_2O_3
Ba_2SrWO_6	$BaSc_2O_4$	$4BaO - 1CaO - 1Al_2O_3$	
$Ba_3Y_2WO_9$	$Ba_3Sc_2WO_9$	$3BaO - 1CaO - 1Al_2O_3$	
$Y_2(WO_4)_3$	Sc_2O_3	$Ba_4Al_2O_7$	
	$Sc_2(WO_4)_3$		

Aluminates can also be supplied with additions of up to 3 wt percent Sc_2O_3.

X-Ray Diffraction Pattern of Barium Calcium Tungstate



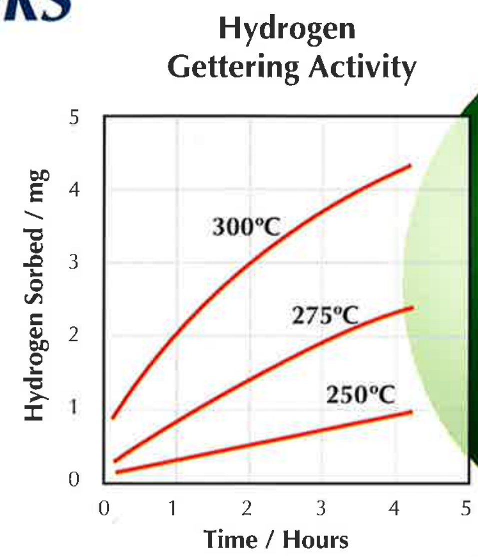
Proprietary and custom blended emission materials can be prepared on request.

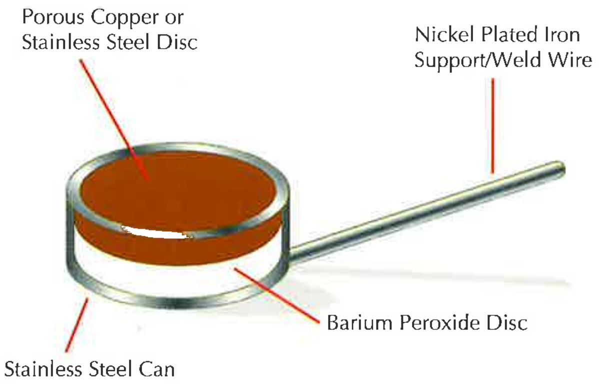
METAL HALIDE LAMP GETTERS

Construction and Operation

The barium peroxide getter for hydrogen developed by APL Engineered Materials finds wide application in metal halide lamps with gas-filled outer jackets. The hydrogen absorption capacity of these getters is significantly greater than that of getters based on zirconium alloys. Barium peroxide maintains a slightly oxidizing atmosphere within the outer jacket in contrast to the reducing atmosphere created by reactive metal getters. The oxidizing atmosphere is effective in removing hydrocarbon contamination which can contribute to end-coat darkening and sodium loss. This is particularly advantageous in metal halide lamps with phosphor-coated outer jackets since these lamps may contain higher levels of residual hydrocarbons.

A solid disc of barium peroxide is contained under a porous copper or stainless steel disc within a stainless steel case. The entire assembly is then crimped together and a lead wire is attached to provide a means for mounting the getter.



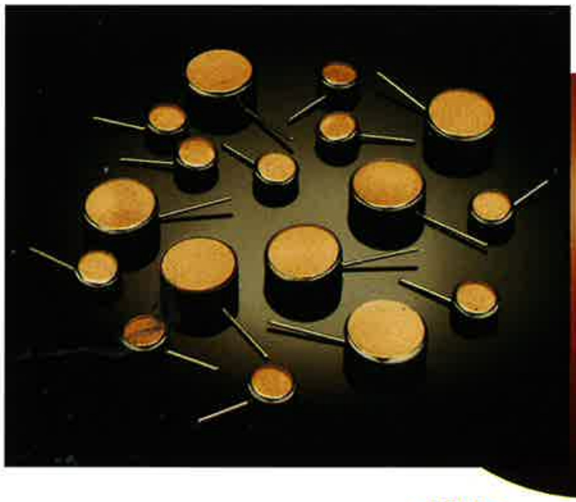


Application

The position of the getter in the lamp is quite important to its proper operation. Its operating temperature should be between 250C and 325C. Within this temperature range the hydrogen gettering rate is high and the oxygen partial pressure is between approximately 0.02 and 1.0 millitorr. Such an oxygen partial pressure is sufficient to oxidize hydrocarbons while avoiding excessive oxidation of metal components within the lamp.

Selection

Two getter sizes are available. The large size is typically used for 175W or higher wattages while the small getter is used for wattages up to 150W. The metal components are fully cleaned and degreased and require no further treatment before use. Barium peroxide getters are shipped in sealed metal containers.



PART DESIGNATION:

GTR / 7.2 / Cu / 0.6 / 8.3

Getter diameter in millimeters
12 for large, 7.2 for small

Porous cover material
Cu for Copper, SS for Stainless Steel

Wire diameter in mm

Length of wire in mm,
12 for large, 8.3 for small

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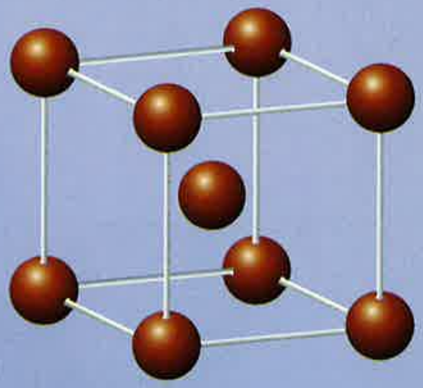
MOLYBDENUM SEALING FOILS

Molybdenum foil, in combination with molybdenum and tungsten wire, is used for the fabrication of electrical lead assemblies for fused silica or "quartz" halogen incandescent filament tubes and high intensity discharge arc tubes. The foil has a unique lens shape to minimize excessive residual strains in the quartz glass which would otherwise occur as a result of forming a glass to metal bond during the high temperature pinch sealing step, and then cooling rapidly to room temperature. Because of its stability at very high temperatures, relatively low thermal expansion coefficient, ductility, and good electrical conductivity, molybdenum is an ideal material for this application.

For certain sealing processes, we offer a potassium silicate doped molybdenum foil which has a higher recrystallization temperature and thus is more resistant to embrittlement during the sealing operation.

Our computerized laser scanning of the cross section of foil products forms the basis for statistical process control and assures our customers that they are receiving the best quality in terms of reliability and functionality for their lamp applications.

Crystal Structure of Molybdenum



Molybdenum forms a body-centered cubic crystal structure. This lattice, common among refractory metals, is a relatively open structure that allows the body centered atom to oscillate at high temperatures. These metals can withstand severe thremal vibrations before melting. Tungsten, molybdenum, tantalum and niobium all have body centered cubic structures.

Standard Foils:

Width† (mm)	Center Thickness (mm)	Max. Edge Thickness (mm)*	Breaking Strength (N)
2.0 ± 0.1	0.0195 ± 0.0015	0.005	≥ 25
2.0 ± 0.1	0.025 ± 0.0015	0.007	≥ 35
2.1 ± 0.1	0.027 + 0.002/-0.003	0.007	≥ 40
2.7 ± 0.15	0.027 + 0.002/-0.003	0.007	≥ 45
3.0 ± 0.1	0.0195 ± 0.0015	0.005	≥ 40
3.0 ± 0.1	0.022 ± 0.0015	0.007	≥ 40
3.0 ± 0.1	0.025 ± 0.0015	0.007	≥ 45
3.0 ± 0.2	0.027 + 0.002/-0.003	0.007	≥ 50
3.0 ± 0.2	0.030 ± 0.002	0.007	≥ 60
4.0 ± 0.2	0.0225 ± 0.0015	0.007	≥ 55
4.9 ± 0.3	0.040 ± 0.002	0.007	≥ 125
5.5 ± 0.3	0.028 + 0.002/-0.003	0.007	> 100
5.5 ± 0.3	0.045 ± 0.003	0.007	> 125

† *Widths greater than 5.5 mm can be quoted as special order.*

* *Measured 0.005 mm from edge.*

Cross-section of Molybdenum Sealing Foil

Edge Thickness: 3 µm
Center Thickness: 24-25 µm

The cross-section of a 2.5 mm molybdenum sealing foil shows the lens-shaped edge profile.

MATERIALS CHARACTERIZATION LABORATORY

APL employs state-of-the-art instrumentation and techniques for chemical and spectroscopic analysis in its Materials Characterization Laboratory.

Precise control of the elemental composition of metal halide mixtures, amalgams, alloys and other lamp materials is essential for proper lamp performance and spectral output. Analysis and certification of chemical composition is routinely performed by inductively-coupled plasma (ICP) emission and atomic absorption (AA) spectrophotometry, as well as automated titrimetric and gravimetric techniques. These same methods are employed in the certification of trace metal impurities at parts-per-million (ppm) and parts-per-billion (ppb) levels. Ultra-dry metal halide materials are certified by coulometric Karl Fischer and mass spectrometric methods for trace water and hydroxide.

Physical properties of materials are also key characteristics in lamp performance and manufacturing. Certifications are routinely performed on sphere mass, sphere strength and particle size distribution of powders.

Other techniques such as ultra-trace metals analyses by spark source mass spectrometry and structural characterization by x-ray diffraction can also be arranged.

Spectroscopic Techniques

- *Inductively Coupled Plasma (ICP) Emission*
- *Atomic Absorption (AA) and Flame Emission*
- *Graphite Furnace AA*
- *UV-Visible Spectrophotometry*
- *Infrared Spectrophotometry*

Electrochemical Techniques

- *Coulometric Karl Fischer Titration*
- *Pulse Voltammetry/Polarography*
- *Ion Selective Electrodes*

Classical Methods

- *Automated Complexometric, Halide and Redox Titrations*
- *Gravimetric/Microbalance Analysis*

Physical Characterization

- *Coulter Counter Particle Size Analysis*
- *Metallography*
- *Thermal Analysis*
- *Sphere Strength Analysis*
- *Hydrogen Gettering Rate and Capacity*

APL ENGINEERED MATERIALS, INC.
OVER 50 YEARS OF SERVICE

An Advanced Lighting Technologies Company

APL Engineered Materials:
50 Years of Contributions to Physics and Discharge Lighting

1944
Anderson Physical Laboratory is founded by Dr. Scott Anderson. Sponsored experimental research in molecular physics begins.

1958
APL begins purification of metal halide salts by zone refining and by reactive gas processing.

1962
Multiple plate vacuum distillation is applied to ultra-purification of alkali metal halide salts.

1964
Ultra-pure sodium iodide is used in metal halide arc tubes. Lamp life triples.

1965
APL develops first processes for producing precisely-sized iodide spheres.

1969
The first bi-component and multi-component metal halide salts are produced. Lamp performance is enhanced.

1969
APL develops methods for producing ultra-dry rare earth iodides.

1971
First sodium-mercury amalgams produced in precisely-sized spheres by APL.

1972
The NaI-ScI_3 phase diagram is published and the compound $NaScI_4$ is proposed and later confirmed.

1981
APL introduces automatic dispenser for amalgam spheres.

1989
Next generation of high-speed sphere dispensers is introduced for both metal halides and amalgams.

1990
APL introduces precision metal pieces for metal halide lamps.

1991
Thermionic emission materials and barium peroxide getters for high intensity discharge lamps are introduced.

1992
Amalgams with precise amounts of mercury are produced for fluorescent lamps.

1994
APL continues growth as a world-class producer of unique discharge lamp materials and components.

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APL ENGINEERED MATERIALS, INC.
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Periodic Table Of The Elements

Solid 🟦
Liquid 🟩
Gas 🟥
Synthetically Prepared ▨

Atomic Number	21
Atomic Weight	44.956
Oxidation State‡	3
Melting Point °C	1541
Boiling Point °C	2836
Density (g/cm³) at 25 °C	2.99
Symbol	Sc
Name	Scandium

1 1.008 ±1 -259.3 -252.8 0.090* **H** Hydrogen																	2 4.003 — -268.9 0.178* **He** Helium
3 6.941 1 180.5 1347 0.53 **Li** Lithium	4 9.012 2 1287 2471 1.85 **Be** Beryllium											5 10.811 3 2075 3650 2.35 **B** Boron	6 12.011 2,±4 3825(subl) — 3.51 **C** Carbon	7 14.007 -3,2,3,4,5 -210.0 -195.8 1.251* **N** Nitrogen	8 15.999 -2,-1 -218.8 -183.0 1.429* **O** Oxygen	9 18.998 -1 -218.6 -188.1 1.696* **F** Fluorine	10 20.180 -248.6 -246.1 0.900* **Ne** Neon
11 22.990 1 97.7 883 0.97 **Na** Sodium	12 24.305 2 650 1090 1.74 **Mg** Magnesium											13 26.982 3 660.3 2519 2.70 **Al** Aluminum	14 28.086 2,4 1414 3280 2.34 **Si** Silicon	15 30.974 ±3,5 44.2 280.5 1.82 **P** Phosphorus	16 32.066 -2,-1,4,6 115.2 444.6 2.07 **S** Sulfur	17 35.453 -1,1,3,5,7 -101.0 -34.0 3.214* **Cl** Chlorine	18 39.948 -189.4 -185.9 1.784* **Ar** Argon
19 39.098 1 63.4 766 0.86 **K** Potassium	20 40.078 2 842 1484 1.55 **Ca** Calcium	21 44.956 3 1541 2836 2.99 **Sc** Scandium	22 47.88 2,3,4 1668 3285 4.50 **Ti** Titanium	23 50.942 2,3,4,5 1910 3421 6.11 **V** Vanadium	24 51.996 2,3,6 1907 2690 7.14 **Cr** Chromium	25 54.938 2,3,4,6,7 1246 2060 7.43 **Mn** Manganese	26 55.847 2,3 1538 2861 7.87 **Fe** Iron	27 58.933 2,3 1495 3100 8.90 **Co** Cobalt	28 58.693 2,3 1455 2920 8.91 **Ni** Nickel	29 63.546 1,2 1084.6 2570 8.95 **Cu** Copper	30 65.39 2 419.5 907 7.14 **Zn** Zinc	31 69.723 1,3 29.8 2403 5.90 **Ga** Gallium	32 72.61 2,4 938.3 2850 5.32 **Ge** Germanium	33 74.922 -3,3,5 615(subl) — 5.78 **As** Arsenic	34 78.96 -2,4,6 221 685 4.79 **Se** Selenium	35 79.904 -1,1,5,7 -7.3 59.5 3.14 **Br** Bromine	36 83.80 -157.2 -153.3 3.749* **Kr** Krypton
37 85.468 1 39.3 688 1.53 **Rb** Rubidium	38 87.62 2 777 1381 2.63 **Sr** Strontium	39 88.906 3 1522 3345 4.47 **Y** Yttrium	40 91.224 3,4 1855 4200 6.51 **Zr** Zirconium	41 92.906 3,4,5 2477 4758 8.57 **Nb** Niobium	42 95.94 2,3,4,5,6 2623 4650 10.28 **Mo** Molybdenum	43 (98) 4,5,6,7 2157 4567 11.5 **Tc** Technetium	44 101.07 2,3,4,6,8 2334 4150 12.41 **Ru** Ruthenium	45 102.906 2,3,4 1964 3760 12.39 **Rh** Rhodium	46 106.42 2,4 1555 2964 11.99 **Pd** Palladium	47 107.868 1,2 961.8 2155 10.49 **Ag** Silver	48 112.411 2 321.1 767 8.65 **Cd** Cadmium	49 114.82 1,3 156.6 2080 7.31 **In** Indium	50 118.710 2,4 231.9 2623 7.27 **Sn** Tin	51 121.757 -3,3,5 630.6 1587 6.70 **Sb** Antimony	52 127.60 -2,4,6 449.5 990 6.25 **Te** Tellurium	53 126.904 -1,1,5,7 113.6 185.2 4.94 **I** Iodine	54 131.29 -111.8 -108.1 5.897* **Xe** Xenon
55 132.905 1 28.4 705 1.90 **Cs** Cesium	56 137.327 2 727 1897 3.62 **Ba** Barium	57 138.906 3 918 3464 6.15 **La** Lanthanum	72 178.49 3,4 2233 4603 13.28 **Hf** Hafnium	73 180.948 3,4,5 3017 5534 16.65 **Ta** Tantalum	74 183.85 2,3,4,5,6 3422 5555 19.3 **W** Tungsten	75 186.207 2,3,4,5,6,7 3186 5650 21.0 **Re** Rhenium	76 190.2 2,3,4,6,8 3033 5025 22.57 **Os** Osmium	77 192.22 2,3,4 2446 4550 22.61 **Ir** Iridium	78 195.08 2,4 1768 4170 21.41 **Pt** Platinum	79 196.967 1,3 1064.2 2856 19.32 **Au** Gold	80 200.59 1,2 -38.8 356.7 13.53 **Hg** Mercury	81 204.383 1,3 304 1473 11.85 **Tl** Thallium	82 207.2 2,4 327.5 1751 11.34 **Pb** Lead	83 208.980 3,5 271.4 1564 9.81 **Bi** Bismuth	84 (209) 2,4 254 962 9.2 **Po** Polonium	85 (210) -1,1,5,7 302 337† — **At** Astatine	86 (222) -71 -62 9.73* **Rn** Radon
87 (223) 1 27 — — **Fr** Francium	88 226.025 2 700 1700† 5.5 **Ra** Radium	89 227.028 3 817 2470 10.07† **Ac** Actinium															
			58 140.115 3,4 798 3443 6.77 **Ce** Cerium	59 140.908 3,4 931 3520 6.77 **Pr** Praseodymium	60 144.24 3 1021 3074 7.01 **Nd** Neodymium	61 (145) 3 1042 3000† 7.26 **Pm** Promethium	62 150.36 2,3 1074 1794 7.52 **Sm** Samarium	63 151.965 2,3 822 1529 5.24 **Eu** Europium	64 157.25 3 1313 3273 7.90 **Gd** Gadolinium	65 158.925 3,4 1356 3230 8.23 **Tb** Terbium	66 162.50 3 1412 2567 8.55 **Dy** Dysprosium	67 164.930 3 1474 2700 8.80 **Ho** Holmium	68 167.26 3 1529 2868 9.07 **Er** Erbium	69 168.934 2,3 1545 1950 9.32 **Tm** Thulium	70 173.04 2,3 819 1196 6.90 **Yb** Ytterbium	71 174.967 3 1663 3402 9.84 **Lu** Lutetium	
			90 232.038 4 1750 4850 11.78 **Th** Thorium	91 231.036 4,5 1572 4227 15.37 **Pa** Protactinium	92 238.029 3,4,5,6 1135 3930 19.05 **U** Uranium	93 237.048 3,4,5,6,7 644 5235 20.45 **Np** Neptunium	94 (244) 3,4,5,6,7 640 3230 19.86 **Pu** Plutonium	95 (243) 3,4,5,6 1176 2600 13.67 **Am** Americium	96 (247) 3,4 1345† — 13.51 **Cm** Curium	97 (247) 3,4 1050 — 14.78 **Bk** Berkelium	98 (251) 3 900† — 15.1† **Cf** Californium	99 (252) 3 860† — — **Es** Einsteinium	100 (257) 2,3 1527† — — **Fm** Fermium	101 (258) 2,3 827† — — **Md** Mendelevium	102 (259) 2,3 827† — — **No** Nobelium	103 (262) 3 1627† — — **Lr** Lawrencium	

Notes
( ) Indicates most stable or best known isotope based upon carbon-12.
* Refers to the gaseous state at 0 °C and 1 atmosphere pressure. Units are g/ℓ.
† Indicates estimated values.
‡ Most common oxidation state is shown in boldface.

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