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**A COMPARISON OF COMMERCIALY AVAILABLE
PRIMARY BATTERY SYSTEMS**

by

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A COMPARISON OF COMMERCIALY AVAILABLE PRIMARY BATTERY SYSTEMS

R. F. Thornton and H. A. Catherino*

To compare energy densities and operating characteristics of small commercially available primary batteries, data from several battery manufacturers have been surveyed. This compilation has been restricted to cells with aqueous electrolytes. Data for representative cell sizes have been tabulated for Leclanché, Alkaline Manganese Dioxide-Zinc, Mercuric Oxide-Zinc, Mercuric Oxide-Cadmium, Monovalent Silver Oxide-Zinc, Divalent Silver Oxide-Zinc, Manganese Dioxide-Magnesium, and Zinc-Air batteries. A list of most of the major manufacturers of these types of batteries has also been compiled.

AgO/ZINC

<u>Cell Type</u>	<u>Dimensions (in.)</u>	<u>Wt (lb)</u>	<u>Nom. Cap. (amp-hr)</u>	<u>Max. Discharge Currents (amp)</u>	<u>Watt-Hr Per Lb</u>	<u>Watt-Hr Per In³</u>
Gould SZR-5LF (Secondary)	1.72 x 0.59 x 3.36	0.231	5	5	39 ⁽¹⁾	2.8 ⁽¹⁾
Gould SZMP-7HE (Primary)	1.72 x 0.59 x 2.89	.219	7	40	48 ⁽¹⁾	3.4 ⁽¹⁾
Yardney PM 3 ⁽²⁾			4.6 ⁽³⁾			2.3
Yardney PM 5 ⁽²⁾			9.5 ⁽³⁾			4.8
Yardney PM 10 ⁽²⁾			15.5 ⁽³⁾			

(1) Based on 10-hour discharge rate.

(2) Pulse capability up to 30 C rate.

(3) At the one-hour rate.

COMMENTS:

The cathode is divalent silver oxide, the anode is zinc, and the electrolyte is aqueous potassium or sodium hydroxide.

The open-circuit voltage is 1.6 to 1.8 volts. At lower rates part of the capacity may be delivered at over 1.7 volts and the remainder at about 1.5 volts.

Recommended storage conditions: (Gould) Dry -32° to 90°F for three years. Wet 32° to 90°, 12 to 18 months for SZR(L) types; 6 to 8 months for SZR types; 48 hours for SZMP types.

Recommended operating conditions: (Gould) 50° to 90°F (0° to 140°F permissible).

Gould manufactures cells from 1 amp-hr to 220 amp-hr in secondary and high rate primary configurations. Maximum energy density quoted is 80 watt-hr/lb and 6.5 watt-hr/in³ for the high rate, 220 amp-hr primary with 48-hour stand life.

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Ag₂O/ZINC

Eveready S76E, 0.455 in diam x 0.200 in height

Volume: approximately 0.03 in³

Weight: 0.08 oz

Recommended drain rate: 0 to 10 ma

Energy Density:

56 watt-hr/lb and 9.4 watt-hr/in³, 1000 ohm load, 127 hr to 1.0 volt, 70°F
55 watt-hr/lb and 9.2 watt-hr/in³, 600 ohm load, 76 hr to 1.0 volt, 70°F

Internal Resistance: 3 to 12 ohms, 40 to 5000 Hz

COMMENTS:

Eveready cell delivers 90% of initial capacity after one year storage at 70°F.

Cells made by Eveready and Mallory range in size from 12 ma-hr to 190 ma-hr.

Eveready S76E delivers about 25% of rated capacity at 0°F, and 5% at -20°F, on a 600 ohm load, 16 hr/day.

The electrolyte is aqueous potassium hydroxide in hearing aid batteries and sodium hydroxide in watch batteries.

Voltage characteristic is flat during most of the discharge. The open-circuit voltage is 1.6 volts and operating voltage is 1.4 to 1.55 volts.

LECLANCHE

Cell Type	Manufacturer and Number ⁽¹⁾	Wt (oz)	Approx. Volume (in ³)	Recomm. Drain Rates (ma)	Flash Current (amp)	Ohms Load	Hours to 0.9 Volt	Watt-Hr Per Lb	Watt-Hr Per In ³ (2)	Amp/hr
AAA	Eveready 912	0.3	0.22	0-20	3.3	750	2 270	30	2.5	1.540
						150	10 30	16	1.4	1.3
AA	Eveready 1015	0.6	0.49	0-25	5.4	300	5 255	35	2.7	1.275
						75	20 45	25	1.9	1.9
C	Eveready 935	1.4	1.5	0-80	3.3	600	3 1300	38	2.2	3.9
						150	10 270	32	1.8	2.7
						30	50 33	19	1.1	1.65
D	Eveready 1150	3.3	3.3	0-150	5.5	300	5 1550	38	2.4	7.75
						75	20 390	39	2.4	7.8
						15	100 59	29	1.8	5.9

- (1) Highest capacity cell listed.
- (2) Based on actual discharge voltage.

COMMENTS:

The cathode is manganese dioxide, the electrolyte is an aqueous solution of zinc chloride and ammonium chloride, and the anode is zinc.

Exposure to temperatures above 125°F causes rapid disintegration of the battery.

Leclanché cells are designed for 70°F; a D cell on 2.25 ohm load gives 25% of its 70°F capacity at 0°F, and no capacity at -20°F.

Eveready makes cells from about 0.05 amp-hr to about 46 amp-hr.

The operating voltage decreases continuously with state-of-discharge. The open-circuit voltage is 1.55 volts, and the operating voltage varies from 0.9 to 1.5 volts depending on load and depth of discharge.

ALKALINE MANGANESE DIOXIDE-ZINC

Cell Type	Manufacturer and Number	Wt (oz)	Approx. Volume (in ³)	Recomm.	Flash Current (amp)	Ohms Load	Hours to 0.9 Volt	Watt-Hr Per Lb	Watt-Hr Per In ³ (1)
				Drain Rate (ma)					
L30 (AAA)	Eveready E92	0.4	0.22	0-100		40	19	25	2.9
L40 (AA)	Eveready E91	0.75	.49	0-150	8.2	1500	1600	32	3.0
						150	165	32	3.0
						10	7.5	29	2.7
L70 (C)	Eveready E93	2.2	1.5	0-480	9.8	100	335	33	3.0
						10	28	27	2.5
L90 (D)	Eveready E95	4.5	3.3	0-650	14	150	1050	33	2.8
						30	210	33	2.8
						5	32	31	2.6
L70 (C)	Mallory MN-1400	2.34	1.5			15	64	34	3.3

(1) Based on actual discharge voltage.

COMMENTS:

The active materials are the same as those in the Leclanché cell. The electrolyte is aqueous potassium hydroxide.

This type of cell will deliver 90% of its initial capacity after one-year storage at 70°F.

The L40 (AA size) cell on a 75 ohm load will deliver 35% of its 70°F capacity at 0°F and 20% at -20°F.

Eveready makes cells from 0.30 to 8 amp-hr.

The operating voltage decreases continuously with state-of-discharge. The open-circuit voltage is 1.5 volts, and operating voltage varies between 1.5 and 0.9 volt depending on drain rate and depth of discharge.

MAGNESIUM-MANGANESE DIOXIDE⁽¹⁾

Cell Type	Approx. Volume (in ³)	Wt (oz)	Ohms Load	Temp (°F)	Hours to 1.0 Volt	Watt-Hr Per Lb	Watt-Hr Per In ³
D	3.3	3.9	15	70	64	46	3.4
			100	70	450	50	3.7
			350	70	1425	46	3.4
			15	20	49	39	2.9
			60	70	90	--	2.7
C	1.5	--	60	70	90	--	2.7

(1) Data from Battery Corporation of America.

COMMENTS:

Open-circuit voltage is 1.8 volts. Initial operating voltage varies from 1.5 to 1.8 volts.

80% of initial capacity retained after 8 months at 130°F; 90% of initial capacity retained after 90 days at 165°F.

D cell will deliver 40% of its 70°F capacity at -20°F on a 60 ohm load and 6.5% at -40°F.

Battery Corporation of America makes C, D, and No. 6 cells.

Maximum current data shown by BCA are 3 amp for each cell. The transient effect is not mentioned.

MERCURY-ZINC

<u>Cell Type</u>	<u>Manufacturer and Number</u>	<u>Wt (oz)</u>	<u>Approx. Volume (in³)</u>	<u>Recomm. Drain Rate (ma)</u>	<u>Ohms Load</u>	<u>Hours to 0.9 Volt</u>	<u>Watt-Hr Per Lb</u>	<u>Watt-Hr Per In³(1)</u>
M40 0.62 in diam x 0.64 in ht	Eveready E1	0.43	0.19	0-100	50	40	41	5.7
					36	28.5	39	5.5
M55 (AA)	Eveready E502	1.05	0.49	0-200	25	47	40	5.4
					12.5	20	33	4.4
M100 ⁽²⁾	Eveready E42N	5.85	3.0	0-1000	5	61	43	5.3

(1) Based on actual discharge voltage.

(2) Slightly smaller than D cell.

COMMENTS:

The cathode is mercuric-oxide, the electrolyte is aqueous potassium hydroxide, and the anode is zinc.

This type of cell will deliver more than 90% of its initial capacity after one-year storage at 70°F.

The cell can be used at 130°F, and operation at 200°F is possible for a short time.

Cells modified for low-temperature service give over 20% of their 70°F capacity at 0°F at the C/90 rate (Mallory). Performance of most other cells falls off seriously at 40°F.

Eveready sells cells from 0.016 to 28 amp-hr. Cells may be purchased from Mallory.

The voltage characteristic is reasonably flat during a large part of the discharge. The open-circuit voltage is 1.35 volts (1.4 if MnO₂ is added to cathode). Operating voltage is 1.2 to 1.3 volts.

GENERAL ELECTRIC MERCURIC OXIDE-ZINC HEART PACER BATTERY

Dimensions:	0.625 in x 0.625 in x 1.4 in
Volume:	0.545 in ³
Weight:	1.4 oz
Nominal Capacity:	3.5 amp-hr
Operating Voltage:	1.3 volts
Energy Density:	55 Watt-hr/lb and 8.6 watt-hr/in ³ at low drain rates, C/1000
Shelf Life:	Preliminary test data indicate an upper limit of 18%/year self-discharge 50 °C and about 40%/year at 65°C
Recommended Discharge Currents:	The cell is designed for 30 μ a. Most of the nominal capacity will be delivered at 75 μ at the C/1000 hour rate
Pulse Capability:	Probably limited only by the internal resistance of about 4 ohms

MERCURIC OXIDE-CADMIUM

Ray-O-Vac (ESB) 600 HC Cell:

Size: 0.986 in max diam, 0.270 in ht
Weight: 0.50 oz
Open-Circuit Voltage: 0.94 volt
Nominal Capacity: 0.60 amp-hr
Operating Temperature Range: -60° to 300°F
Energy Density: 17 watt-hr/lb and 3.0 watt-hr/in³ under optimum conditions
Recommended Current Range: 0 to 150 ma (loss of utilization above 50 ma)
Shelf Life: 5% capacity loss after 5 1/2 years at 70°F
30% capacity loss after 2 years at 113°F
Pulse Capability: Probably limited only by the internal resistance of 0.3 to 0.8 ohm

ZINC-AIR

<u>Cell Type</u>	<u>Dimensions</u>	<u>Wt (oz)</u>	<u>Volume (in³)</u>	<u>Recomm. Current (amp)</u>	<u>Ohms Load</u>	<u>Hr to 0.9 Volt at 75°F</u>	<u>Watt-Hr Per Lb</u>	<u>Watt-Hr Per In³</u>
Ray-O-Vac P-C-8	1.032 in x 1.032 in x 1.828 in	(2)	1.95	0-1.5	2.0	14	85-95 ⁽¹⁾	4.0
					0.72	3.2		2.0
AA Hitachi Maxell (Leesona Moos)		(2)	0.49	0-0.5	(25 ma)	84		5.1
					(260 ma)	7.7		4.1
Leesona Moos 410	1.5 in x 0.33 in x 0.75 in	0.39	0.37	0-1	(400 ma?)	--	120 ⁽¹⁾	8 ⁽¹⁾

- (1) Claimed.
(2) Not given.

COMMENTS:

The open-circuit voltage is 1.5 volts. The operating voltage is 0.9 to 1.2 volts depending on load.

The cathode is oxygen from the air, the anode is zinc, and the electrolyte is aqueous alkali hydroxide.

Operating temperature range is -20 to +125°F (Ray-O-Vac).

Storage life sealed is 18 months at 75°F (Ray-O-Vac).

Activated stand life is 170 hours minimum at 75°F, and greater if air access is restricted (Ray-O-Vac).

Ray-O-Vac makes 2 amp-hr 0.45 in³; 3 amp-hr 0.63 in³; 8 amp-hr 1.95 in³; and 16 amp-hr 4.25 in³ single cells and larger battery stacks.

Leesona-Moos markets an AA cell, a 5 amp-hr 0.62 in³ cell; an 8 amp-hr 1.24 in³ cell; and a 2.5 amp-hr 0.37 in³ cell.

BATTERY MANUFACTURERS

The following is a list of manufacturers of primary and high-energy density batteries. Most of the major manufacturers are included, although the list is not complete. The battery types listed under each manufacturer are sold by them, but in some cases -- such as the mercury-zinc cell -- they may be purchased from another company.

Battery Corporation of America
43 West Front St., Red Bank, N.J. 07701

Magnesium-Manganese Dioxide

Eagle-Picher Industries, Inc.
959 American Blvd., Cincinnati, Ohio 45202

"Specialty" Batteries

Electrochimica Corp.
1140 O'Brien Drive, Menlo Park, Calif.

Silver-Zinc, Silver-Cadmium, Mercury-Cadmium, Non-Aqueous

ESB Incorp., Exide Missile and Electronics Div.
P.O. Box 11301, Raleigh, N. Car. 27604

Silver-Zinc (primary and secondary),
Silver-Cadmium

ESB Incorp., Ray-O-Vac Div.
212 Washington Ave., Madison, Wisc. 53703

Leclanché, Alkaline Manganese Dioxide-Zinc,
Mercury-Zinc, Silver Oxide-Zinc, Zinc-Air

Gould Inc., Burgess Div.
P.O. Box 3140, St. Paul, Minn. 55165

Leclanché, Alkaline Manganese Dioxide-Zinc,
Mercury-Zinc, Gelled Lead-Acid, Nickel-Cadmium,
Silver Zinc (primary and secondary),
Zinc-Air

Gulton Industries, Inc., Battery and Power Sources
Div.
212T Durham Ave., Metuchen, N.H. 08840

Silver-Zinc, Nickel-Cadmium

Leesona Moos, Laboratories Div.
Lake Success Park, Community Drive, Great Neck,
N. Y. 10021

Zinc-Air

Mallory Battery Co., a div. of P. R. Mallory & Co., Inc.
S. Broadway, Tarrytown, N. Y. 10591

Mercury-Zinc, Alkaline Manganese Dioxide-Zinc,
Monovalent Silver Oxide-Zinc (primary), Solid
State (Lithium)

Union Carbide Corporation, Consumer Products Div.
270 Park Ave., New York, N. Y. 10017

Leclanché, Alkaline Manganese Dioxide-Zinc,
Mercury-Zinc, Monovalent Silver Oxide-Zinc
(primary), Nickel Cadmium, Lead-Acid

Whittaker Corporation, Power Sources Div.
3850 Olive, Denver, Colo. 80207

Silver-Zinc, Silver-Cadmium

Yardney Electric Corp.
82 Mechanic St., Pawcatuck, Conn. 02891

Silver-Zinc, Silver-Cadmium