

Feasibility Study for Appliances

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16.1 BATTERY-OPERATED APPLIANCES

An immense variety of electric appliances is offered today. A significant number of these can optionally or exclusively be operated with batteries. The applications cover all fields, ranging from industrial to domestic and hobby applications. The advantages of battery-powered appliances are obvious: The user can operate a device independently of mains supply anywhere desired. A power cord is not necessary as the power source, the battery, is incorporated in the device.

While well-constructed devices are produced and sold in great numbers, others prove to be unsaleable and thus dead stock. The reason for this is often the use of a battery that is unsuitable for one of the following reasons:

- An inconvenient electrochemical system was chosen.
- The battery was not dimensioned correctly.
- Wrong presumptions regarding the battery's properties or the energy content were made.

A battery-powered device is said to be well designed when it resembles a mains-operated one in function as closely as possible.

While power consumption has only since the energy crisis become an important subject for mains-dependent appliances, it must be minutely treated and minimized when battery powering is demanded.

The goal is perfect function of the appliance with the lowest possible power consumption.

The engineer or designer of any appliance should exhaust all possibilities of lowering power consumption by raising the efficiency of a device with sophisticated electronics and modern materials before deciding which battery to use. A substantial amount of energy can be saved by these means.

Only when the design is ready and optimized, a load profile and power demand of the appliance can be issued. Now the task is installation of a small and cost effective but big enough battery. To take care of this task a great amount of experience is necessary.

Table 16.1 shows a selection of the most important applications. Primary button cells normally cover the load range from μA to mA . The mA range can be covered by primary and by secondary cells. For heavy loads in the A range mostly secondary batteries are chosen.

16.2 CALCULATIONS TO ESTIMATE CAPACITY

Battery-powered appliances with only very few exceptions are operated with direct current, so the experienced or calculated power consumption can be defined as

$$N = U \times I(W)$$

with U = operating voltage of the appliance = discharge voltage of the battery = average discharge voltage, and I = current consumption of the appliance = discharge current of the battery.

Taking the efficiency (η) into consideration the nominal power output of the appliance amounts to

$$N = U \times I \times \eta$$

The calculated power output is only to be regarded as an average value with a variance of $\pm 20\%$. Causes for this are

- The batteries do not have similar power characteristics (exception: very low loads).
- The battery's voltage drops continuously during discharge.
- The discharge current changes due to voltage dropping and the appliance's load profile changes.

It is important that the appliance's operation is satisfactory even when power yield is low with the battery becoming discharged.

As described in Chapter 15, new primary cells and fully charged accumulators have a nominal system-specific voltage value at the beginning of the discharge. (See Table 15.3). The voltage drops as time passes from the nominal voltage over the average voltage to the cut-off voltage, as Figure 16.1 shows.

The number of cells needed for an appliance can be calculated as follows:

$$\text{Number of cells} = \frac{\text{Nominal voltage of the appliance}}{\text{Nominal voltage of the chosen system}}$$

The nominal voltage of the appliance is identical with the battery's nominal voltage. During the battery's discharge the voltage drops permanently. Of course the

Table 16.1 Review of the most common important applications with load range data and voltage rating.

Application	Common nominal voltage V	Load range $\mu\text{A}/\text{mA}/\text{A}$	Discontinuous use yes/no
Cranking and starting	6.0 to 12.0	A	Yes
Wristwatches	1.2 to 2.4	μA , mA	No
Dictaphones	2.4 to 8.4	mA	No
TVs, radios, recorders	3.6 to 24.0	mA, A	Yes
Remote controls	4.8 to 12.0	mA	No
Filming equipment	4.8 to 12.0	mA	No
Film lighting	6.0 to 42.0	mA, A	No
Cameras	1.2 to 4.8	mA	No
Flashlights	2.4 to 12.0	mA, A	Yes
Walkie-talkies	4.8 to 12.0	mA	Yes
Garden appliances	3.6 to 7.2	mA, A	Yes
Handheld flashlights	2.4 to 6.0	mA, A	No
Hobby (airplanes, boats, cars)	1.2 to 12.0	mA, A	No
Hearing aids	1.2 to 2.4	μA , mA	No
Machine and device controls	2.4 to 24.0	mA	Yes
Medical equipment	1.2 to 12.0	mA	No
Measuring instruments	1.2 to 12.0	μA , mA	Yes
Models (airplanes, boats, cars)	1.2 to 12.0	mA, A	No
Motorcycle blink lights	2.4 to 6.0	A	Yes
Shaving sets	2.4 to 4.8	mA	No
Intercom systems	1.2 to 6.0	mA	No
Safety lights and illumination	2.4 to 12.0	mA	No
Miscellaneous toys	1.2 to 9.0	μA , mA	No
Pocket flashlights	1.2 to 4.8	mA	No
Pocket calculators	1.2 to 6.0	μA , mA	No
Clocks, signal and warning devices	2.4 to 24.0	mA, A	No
Continuous memory power supply	1.2 to 24.0	μA , mA, A	Yes
Tools (drills and cutters)	2.4 to 12.0	mA, A	Yes
Toothbrushes	1.2 to 2.4	mA	No
Bicycle lighting	2.4 to 6.0	mA	No

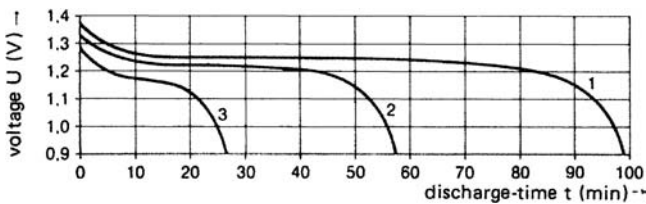


Figure 16.1 Voltage characteristics of a sealed cylindrical NiCd cell with sintered electrodes under different loads (1 = $6 \times$ nominal current; 2 = $10 \times$ nominal current; 3 = $20 \times$ nominal current).

load is a major factor for this voltage drop (see Figure 16.1). The major influences are

- The specific behavior of the chosen electrochemical system and the battery's construction.
- The ratio of on-load current to battery capacity.
- Period of time of discharge, which is the condition of charge at the moment of evaluation.
- The ambient temperature when varying strongly from standard conditions.

The equation for nominal power output is to be fitted with the mean voltage instead of the nominal voltage, as the voltage is load dependent (see Figure 16.1).

The value for the mean discharge voltages given in Table 15.3 is similar to that experienced with domestic appliances and can therefore be employed for most calculations.

Table 15.3 also advises certain cut-off voltages. Battery-powered appliances should operate properly at least up to these cut-off voltages.

Table 15.3 also shows that certain electrochemical systems, given, the same size are interchangeable, e.g. a lithium cell can replace two carbon-zinc (dry) cells or two silver oxide cells; the same goes for three lead-acid cells compared to four alkaline manganese cells. In real life this is only possible to some extent, as certain specific properties of different electrochemical systems regarding their on-load characteristics, their energy content, and special constructive details resist this interchange. Two or three alternatives can always be found and should be evaluated.

While in pre-electronic times the nominal voltage of any electrical set was usually standardized to some low voltage value, nowadays any voltage above 1.2 V can be chosen, because electronic circuitry can equalize. Of course the nominal voltages of the different electrochemical systems must be respected. Therefore nominal voltage of a set is the product of the number of cells in series and the nominal voltage of the chosen battery system.

Sometimes faulty specifications are ignorantly made; this can easily be misunderstood: e.g. a nominal voltage of 4.8 V can sometimes be found on four alkaline primary cells. This value is incorrect as it was derived from the mean discharge voltage. The correct value is 6 V. Whenever the number and type of cells is clearly defined in the specification of an appliance, no doubts are possible.

Criteria for the nominal value and thus the number of cells are

- The demanded power output of the appliance.
- The demanded operational time for a set of batteries.
- The allowed size of the set, that is the available space for the batteries.

Sets with very low power consumption, that is in the μW and the lower mW range, are sufficiently powered by one or two cells. Miniature devices like wristwatches do not in any case incorporate enough room for several cells. Appliances of higher energy demand are more economic when operated on higher voltage. The most important fields of application are listed in [Table 16.1](#) with their nominal voltages, as they are common in present-day appliances.

16.3 CAPACITY OF A BATTERY

The ability to do work is not specified in Wh as is common in the technical world. Specifications of this kind are only common in general presentations of electrochemical systems (see Figure 16.2). As the voltage characteristics of a cell are determined by the electrochemical system and the load is highly variable, batteries are classified by their ability to supply a certain amount of current in a certain period of time until the cut-off voltage is reached. This value is called “the capacity of a battery” and is given in mAh or Ah . The capacity of a battery is not a constant value.

Capacity and load capability of a battery are dependent on

- The electrochemical system.
- The construction.
- The volume of the battery.
- The type of load (see Section 16.4).

Generally,

- Higher discharge current results in a smaller rated capacity.
- The specified nominal capacity mostly defines the maximum capacity.

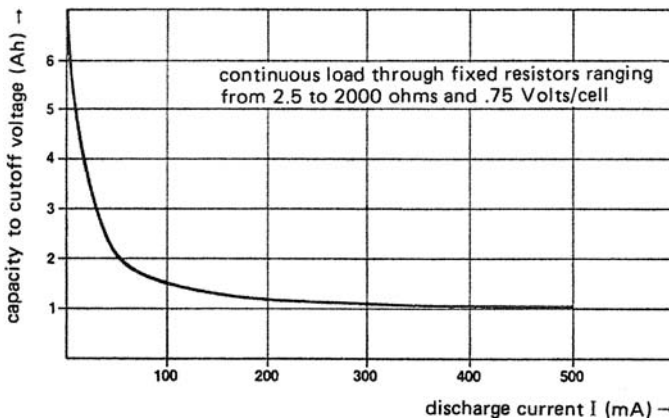


Figure 16.2 Capacity of a mono cell (Leclanché type) dependent on the load.

The possible variance of the rated capacities is shown in [Figure 16.2](#). While with a load of about 30 mA, at least 4 Ah can be drawn resulting in a total time of operation of 133 hours until the cut-off voltage is reached, under a load of 200 mA only 1 Ah can be drawn. Apart from this the mean discharge voltage under high loads is very low. We are talking about a battery system that is only advisable for small loads.

To match the capacity of a battery with given number of cells and nominal voltage, the operating time for exclusive battery powering and the current consumption values must be derived. The operating time can amount to hours, days, or years, but must be expressed in hours as the capacity is specified in mAh or Ah.

The mean discharge current can be approximated by the nominal power output; this system is only satisfactory when the current load is steady. Under more-or-less discontinuous load practical tests with samples of the new design are necessary. Through these generated load profiles conclusions to the final battery design are made.

16.4 THE MOST IMPORTANT LOAD PROFILES OF ELECTRIC APPLIANCES

16.4.1 Continuous Current Load

This type of load is at hand when the load current is completely continuous or only shortly disrupted by impulsive changes up to 100% of the continuous value. Load current multiplied by the desired operating time results in the battery capacity; for current spikes the capacity estimate is raised by 2 to 10%.

If for instance an electronic memory bank with a continuous power consumption of $7\mu\text{A}$ must be protected for at least 3 months, a battery with a capacity of $2200\text{ hours} \times 7\mu\text{A}$ is necessary. As the voltage is not allowed to drop below 1.2 V during operation, two primary button cells or two nickel/cadmium cells must be prescribed. A lithium cell would also do the job.

16.4.2 Intermittent Current Load

Whenever the load profile shows that the occurring current load changes can be five times the nominal value, the necessary battery capacity can accurately enough be approximated to be the mean load current value. The mean load current value in the given example, which accords to the loads occurring in some measuring equipment, is about 1.4 times I_N . With increasing duration of these peak loads the mean current load rises; this multiplied by the expected operating period results in the battery's capacity. With proceeding discharge it must be tested, however, whether the battery's voltage range is satisfactory ([Figure 16.3](#)). Even when peak loads are encountered the voltage must not drop below the specific cut-off voltage.

16.4.3 Severely Intermittent Load

Whenever current variations exceed five times the nominal value (for example $10 \times$; see [Figure 16.4](#)), the magnitude of these peaks are a base for dimensioning the battery or otherwise the power loss of the battery would not be sufficiently taken into consideration. The load of the nominal current must additionally be considered.

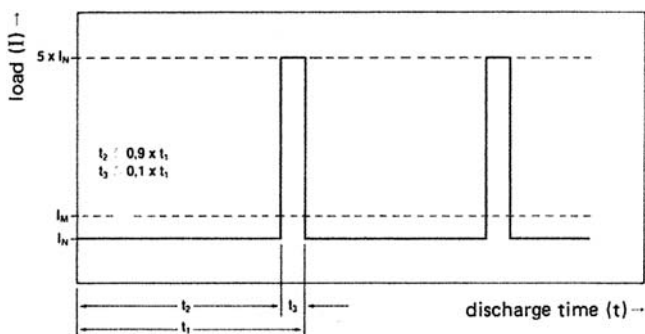


Figure 16.3 Simplified diagram of a load profile for an electric appliance with intermittent current load.

An intelligible example for this load characteristic is shown in Figure 16.4 for a wireless set, where in receiving operation the nominal current I_N is consumed, while in transmitting operation 10 times I_N is demanded for at least 10% of the operational time. A battery that reliably covers the operating-type “transmission” must be chosen; for the whole operating period it must remain above the lower voltage limit.

Example:

- Wireless set nominal voltage: 12 V
- Device rated current: 10 mA (receiving)
- Maximum load: 300 mA (transmitting)
- Desired operating time: 10 h
- Receiving: 90%
- Transmitting: 10%
- Operating voltage 7.2 to 12 V:
- Necessary capacity: $1 \times 300 = 300 \text{ mAh}$ plus $9 \times 10 = 90 \text{ mAh}$ results in 390 mAh

Thus a battery of 400 mAh is necessary for 1 hour’s operation. The voltage may not drop below cut-off voltage after 1 hour’s use with 400 mAh.

Eight primary cells of the alkaline type of eight NiCd accumulators fit these specifications.

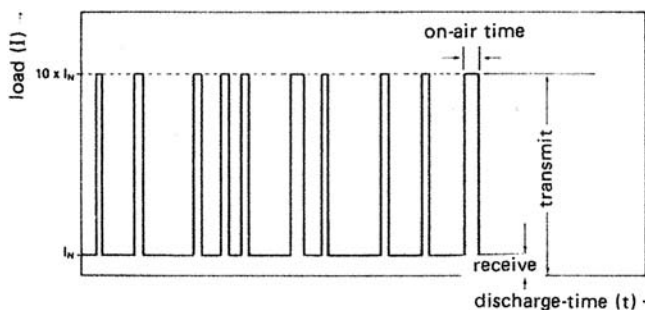


Figure 16.4 Simplified load profile of a wireless set; on-air time about 10% of the receiving time.

16.4.4 Short Peak Currents

Dimensioning a battery is much simpler when a relatively constant load (see Section 16.4.1) with short current peaks of up to 2 seconds, for instance to activate a signal, exist. The permanent current can in these cases derive the battery's size because short peaks do not influence the battery's capacity too much. It must be tested, however, whether the peaks cause a voltage drop below the cut-off value. Whenever this is the case, a larger battery than necessary on first sight or a battery of different design must be chosen.

16.5 INFLUENCE OF SELF-DISCHARGE AND TEMPERATURE

16.5.1 Self-Discharge

Every battery is during storage subject to self-discharges. The self-discharge rate of modern primary batteries is very low and negligible in most cases even when the appliance is not frequently used and deactivated in between. The storage life of common NiCd batteries is about 2 years. For batteries with a predestined operational time of 2 years an additional 2 to 10% of the capacity necessary for operation is sufficient to compensate self-discharge losses.

Lithium batteries have an essentially longer shelf-life. The self-discharge rate is lower than with electrochemical systems on a zinc basis and amounts to less than 1% per year. In case that long-term tests confirm these values, a permitted shelf-life of up to 10 years results.

Rechargeable accumulators, on the other hand, that are nickel/cadmium and lead-acid batteries have a higher self-discharge rate than primary cells. The reason for this is that secondary cells often are less stable electrochemical systems than primary cells, which is partly dependent on the design. When planning with a rechargeable battery the self-discharge rate must therefore be respected. This self-discharge is lowest with nickel/cadmium cells with mass electrodes, while cells with sintered electrodes may lose up to 1% of the nominal capacity per day (see [Figure 16.5](#)).

Self-discharge however must not be taken into consideration when the accumulator is discharged within a few days after loading. Whenever this is not the case, a lower capacity level must be coped with or the accumulator must be recharged directly before discharge. Accumulators have the great advantage, compared to primary cells, to be rechargeable several hundred times.

16.5.2 Influence of Temperature

General electrochemical systems work optimally between 15 and 25°C. Typical characteristics change at higher temperatures, for instance discharge behavior improves while others such as rechargeability and self-discharge deteriorate. Limit for economic battery operation is about 65°C. Naturally batteries can be operated above this temperature if over-proportional reduction of lifetime can be accepted.

Temperatures of less than 15°C cause capacity to drop and at low temperatures under -10°C primary cells on a zinc basis cannot be efficiently applied, except when a fraction of the nominal capacity is sufficient. Lithium batteries still show good load capability at -20°C. The accumulator's capacity in

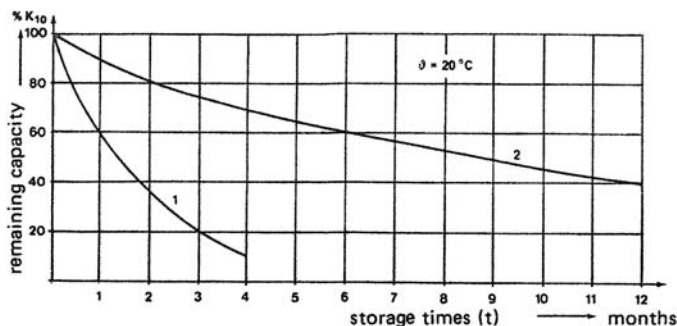


Figure 16.5 Self-discharge of NiCd accumulators with sintered electrodes (1) and mass electrodes (2).

general deteriorates but some designs like the NiCd series with sintered electrodes are still applicable to -45°C . Rechargeability is at these temperatures very poor except if the charging device is sophisticated enough to compensate this.

The following is a simplified summary of temperature limits for certain applications of portable batteries:

1. Primary cells on a zinc basis -10°C to $+50^{\circ}\text{C}$
With alkaline electrolyte -20°C to $+50^{\circ}\text{C}$
2. Lithium primary battery -20°C to $+60^{\circ}\text{C}$
Special designs -40°C to $+110^{\circ}\text{C}$
3. Accumulators
Lead-acid batteries, discharge -20°C to $+50^{\circ}\text{C}$
NiCd batteries, discharge -45°C to $+60^{\circ}\text{C}$
Charging action above 0°C

Figure 16.6 shows the available capacity of two different NiCd cells dependent on the temperature.

16.6 DESIGN REQUIREMENT STUDY

- Estimate required power (experience).
- Determine nominal voltage.
- Ascertain load current through calculation and through testing.
- Prepare a load profile; ascertain I_N and $I_{\max}$.
- Determine operating period per set of batteries (h).
- Calculate capacity: $C = I \times t$.
- Consider storage and temperature conditions.
- Choose an adequate electrochemical system, note load capability and profile.
- Determine number of cells.
- Undertake practical tests to make sure that under all circumstances the battery's voltage is always sufficient during the demanded operational period.

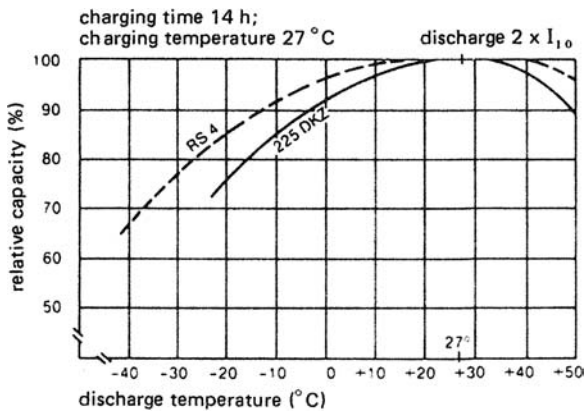


Figure 16.6 Available capacity of NiCd cells when discharged with twice the nominal current vs. temperature range (RS 4 = cell with sintered electrodes; 222 DKZ = cell with mass electrodes).

16.7 DESCRIPTION OF AVAILABLE PORTABLE BATTERIES

In the near future this already vast spectrum of available batteries will become even greater, with about five to ten variants of lithium batteries having been patented and some already available on the market. The different electrical systems are condensed in Table 15.4.

Data important to the designer for the most important designs follows in short, divided into primary cells and secondary cells (accumulators). For project work, these data are of course by no means sufficient, but the relevant industry will provide abundant descriptive literature.

16.7.1 Primary Cells

System: Zinc/Carbon (Leclanché)

- Nominal voltage: 1.5 V/cell
- Mean discharge voltage: 1.2 V/cell
- Cylindrical cells in international standardized sizes and two or three qualities
- Maximum capacity about 7.5 Ah
- Standardized and flat cell batteries for special applications up to 4.0 Ah available
- Temperature behavior: inefficient at low temperatures, about 20% capacity available at -10°C
- Storage life: 12 to 24 months

Examples of application: recorders, radios, dictaphones, filming equipment, tooth-brushes, shaving sets, flashlights, watches, hobby devices, toys, etc.

System: Zinc/Carbon (Alkaline)

- Nominal voltage: 1.5 V/cell
- Mean discharge voltage: 1.2 V/cell
- Button cells from 40 mAh to 300 mAh
- Cylindrical cells (Alkaline manganese batteries) and flat cell batteries in internationally standardized sizes
- Maximum capacity: 10 Ah
- Temperature behavior: applicable to -20°C at 30% capacity
- Storage life: 24 months

Examples of application: recorders, radios, dictaphones, remote controls, pocket calculators, toothbrushes, walkie-talkies, flashlights, toys, etc.

System: Zinc/Mercury Oxide

- Nominal voltage: 1.35 V/cell
- Mean discharge voltage: 1.2 V/cell
- Button cells of 20 mAh to 1000 mAh
- Temperature behavior: applicable from -10°C to 60°C
- Storage life: 24 months and more

Examples of application: hearing aids, cameras, etc.

See Table 16.2 for a summary of available electrochemical systems.

System: Zinc/Silver Oxide (Valence: 1)

- Nominal voltage: 1.55 V/cell
- Mean discharge voltage: 1.4 V/cell
- Button cells from 12 mAh to 180 mAh
- Temperature behavior: applicable from -10°C to 60°C
- Storage life: 24 months and more

Examples of application: wristwatches, hearing aids, etc.

System: Zinc/Silver Oxide (Valence: 2)

- Nominal voltage: 1.5 V/cell
- Mean discharge voltage: 1.2 V/cell
- Button cells from 30 mAh to 90 mAh
- Temperature behavior: applicable from -10°C to 60°C
- Storage life: 24 months and more

Examples of application: wristwatches, hearing aids, etc.

System: Zinc/Air (with Acidic Electrolyte)

- Nominal voltage: 1.45 V/cell
- Mean discharge voltage: 1.15 V/cell
- Cylindrical cells and batteries up to 70 Ah
- Temperature behavior: applicable from -10°C to 60°C
- Storage life: 12 months and more

Table 16.2 Summary of available electrochemical systems with relevant data for the possible energy density per cm³.

Electrochemical system	Nominal voltage V	Energy density mWh/ccm	Remarks
Carbon/Zinc Leclanche system	1.5	120–190	Primary cell as button, cylindric, or prismatic cell
Carbon/Zinc alkaline	1.5	200–300	Primary cell as button, cylindric, or prismatic cell
Zinc/Mercury oxide	1.35	400–520	Primary battery in button cell design
Zinc/Silver oxide valency: 1 or 2	1.55	350–650	Primary battery in button cell design
Air/Zinc with acidic electrolyte	1.45	200–300	Primary battery in cylindric design
Air/Zinc with alkaline electrolyte	1.4	650–800	Primary battery in button design
Lithium/Manganese dioxide	3.0	500–800	Primary battery button and cylindric cell
Nickel/Cadmium	1.2	40–80	Accumulator: button, cylindric, and prismatic designs
Lead/Lead dioxide	2.0	50–100	Accumulator; cylindric and prismatic designs

Examples of application: hearing aids, etc.

System: Zinc/Air (Alkaline)

- Nominal voltage 1.4 V/cell
- Mean discharge voltage: 1.2 V/cell
- Button cells up to 400 mAh
- Temperature behavior: applicable from – 10 °C to 60 °C
- Storage life: self-discharge less than 1% per year
- Activation only after contact with air

Examples of application: garden and farm appliances, electric fences, warning lights for roads under construction, etc.

Lithium Systems

- The most well known are lithium/manganese-dioxide, lithium/sulfur dioxide, lithium/copper oxide, and lithium/thionyl chloride
- Nominal voltages: from 1.5 to 3.8 V
- Button cells and cylindrical cells up to about 12 Ah
- Temperature behavior: partly also applicable with extreme temperatures
- Storage life: self-discharge less than 1% per year up to 10 years

Examples of application: calculators, film cameras, wristwatches, etc.

16.7.2 Secondary Cells, Accumulators

System: Nickel/Cadmium (with Mass Electrodes)

- Nominal voltage: 1.2 V/cell
- Button cells from 10 mAh to 1000 mAh
- Storage life: practically unlimited
- Temperature behavior: discharge -20°C to 45°C (60°C); charging: 0°C to 45°C

Examples of application: calculators, razors, flashlights, and memory back-ups

System: Nickel/Cadmium (with Sintered Electrodes) and Nickel/Metal Hydride

- Nominal voltage: 1.2 V/cell
- Cylindrical cells from 100 mAh to 7 Ah
- Prismatic cells from 2.4 Ah to 12 Ah
- Storage life: practically unlimited
- Temperature behavior: discharge -45°C to 65°C (75°C); charging: -20°C to 20°C . Special designs rated for high voltage and high temperature application.

Examples of application: tools, flashlights, models, walkie-talkies, cranking and starting, etc.

System: Lead-Acid (VRLA)

- Nominal voltage: 2.0 V/cell
- Prismatic and cylindrical batteries in 2-, 4-, 6-, and 12-V units from 1 Ah to 63 Ah
- Storage life: recharge after 12 months
- Temperature behavior: -30°C to 50°C

Examples of application: alarm systems, tape recorders, tools, portable lighting equipment, cranking and starting, etc.

System: Lithium-Ion

Examples of application: mobile phones, video cameras, laptops, etc.

16.8 NATIONAL AND INTERNATIONAL STANDARDIZATION

The most important portable batteries are nationally and internationally standardized. The engineer should under all circumstances take these standardized types into consideration (see Chapter 14).

Apart from the trading names the specifications of the IEC (International Electrotechnical Commission) are most commonly used, especially by European manufacturers. These IEC standards are superior to all other standards and specify the maximum overall sizes. The designer of an appliance should therefore make the battery compartment big enough to take batteries of these IEC standards, but also consider smaller batteries at the lower tolerance limit of the IEC standards, but also consider smaller batteries at the lower tolerance limit of the IEC standards and make

Table 16.3 Survey of the most important standardized cylindrical cells.

Trade specification	Lady	Micro	Mignon	Baby	Mono
Sizes:					
Height in mm (max.)	30,2	44,5	50,5	50,0	61,5
Diameter in mm	12,0	10,5	14,5	26,2	43,2
	(− 1,3)	(− 1)	(− 1)	(− 1,5)	(− 2)
IEC spec. up to IEC 86-2	R/1	R 03	R 6	R 14	R 20
ANSI spec. (USA)	g N	AAA	AA	C	D
JIS spec. (Japan)	UM 5	UM 4	UM 3	UM 2	UM 1
DIN-IEC No.:	86-2	86-2	86-2	86-2	86-2

sure they are usable without contacting difficulties. This prevents bad surprises (see Tables 16.3, 16.4, and 16.5). The given heights in Table 16.3 are overall lengths including the contact buds.

The commonly used multi-cell dry batteries are also standardized; the “standard 4.2 V battery” and the “energy block 9 V” unfortunately are standardized only by IEC and DIN. The program of types of common dry cells, as far as standardized sizes are concerned, is still somewhat clear. Concerning button cells, development is at full pace; new cells with different sizes and technical specifications are introduced to follow development of appliances. Main reasons for this are extremely small cells and extremely long life.

The different electrochemical systems have been treated in Section 16.9.

16.9 THE INTERCHANGE-PROGRAM NiCd CELLS AND PRIMARY CELLS

For the most common dry cells identically sized rechargeable nickel/cadmium accumulators, which are rechargeable several hundred times, can be provided. The recharging process's costs are negligible and the use of these batteries is only economic in case of a considerable need of dry cells. The consumer can only be

Table 16.4 Standardized commercial primary cells with 4.2 and 9 V.

Commercial name	Standard 4.5 V battery	Energy block 9 V
Dimensions:		
Height in mm	67	48,5
Length in mm	62	26,5
Width in mm	22	17,5
IEC specification	3 R 12	6 F 22
DIN IEC No.	86-2	86-2

Table 16.5 Survey of the most common standardized button cells.

Dimension:							
height (mm)	6.2	5.4	4.2	3.6	3.6	5.4	3.6
diameter (mm)	6.0	11.6	11.6	11.6	9.5	7.9	7.9
IEC specification	MR 9	MR 44	MR 43	MR 42	MR 45	MR 48	MR 41
(examples)	LR 9	SR 44	SR 43	SR 42	SR 45	SR 48	SR 41
ANSI specifications	—	WM 15	WM 11	WM 10	—	WM 6	WM 5
(examples)	—	WS 15	WS 90	WS 12	—	WS 5	WS 4
JIS specifications	—	HS—C	—	HS—B	—	HS5	GS3
(examples)	—	G 13	G 12	—	—	G 5	—
DIN specifications	R 9	SR 44	SR 43	MR 42	—	—	SR 41
(examples)	—	—	—	—	—	—	—
DIN-IEC No.:	86-2	86-2	86-2	86-2	—	—	86-2

advised to employ NiCd accumulators when at least every two or three weeks a new set of dry cells would be necessary. Costs of the NiCd cells plus the charging device should not exceed that of one year's battery consumption.

An overall comparison of the energy content of dry cells and NiCd accumulators is not possible as these cells show very different characteristics. While small dry cells may have up to three times the energy content of sealed NiCd cells, the energy content of larger dry cells may only be two or three times greater. This comparison is positively influenced for the sealed NiCd cells when low temperature characteristics or heavy load situations are considered. To enable the user to get an estimated comparison Table 16.6 presents the IEC standards and the nominal capacity values of NiCd cells; statements regarding the energy content of dry cells of the same size are also made.

Table 16.6 Comparison of capacity ratings of dimensionally comparable NiCd accumulators and dry cells.

Size designations for dry cells	Dry cells		NiCd accumulators		
	IEC standards designation	Rated capacity mAh	IEC standard designation	Nominal capacity current	
				mAh	mA
Button cell	SR 48	70	KBL 8/6	10	1
Button cell	NR 07	210	KBL 12/6	20	2
Button cell	NR 9	360	KBL 16/7	60	6
Transistor battery	6F 22	500	—	100	10
Lady cell	LR 1	580	KR 12/30	150	15
Micro cell	LR 03	750	KR 10/44	180	18
Mignon cell	LR 6	1500	KR 15/51	500	50
Baby cell	LR 14	5000	KR 27/50	1800	180
Mono cell	LR 20	10000	KR 35/62	4000	400

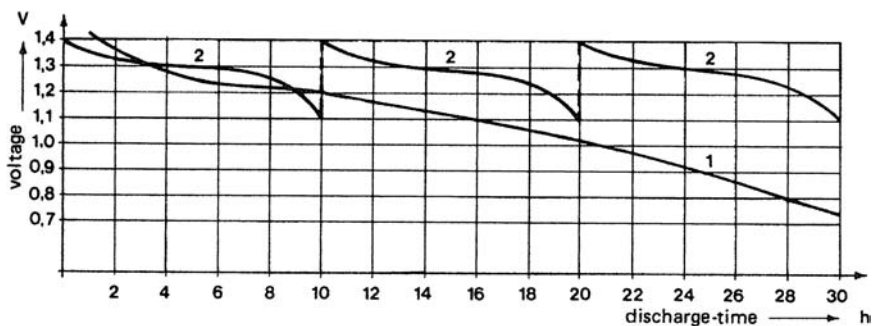


Figure 16.7 Comparison of the discharge curves of a dry cell battery and a NiCd accumulator. Curve 1 = discharge of a dry cell (mignon-sized alkaline). Curve 2 = discharge of a NiCd cell of the same size.

While nominal capacities are specified for NiCd accumulators, which correspond approximately with the drawable capacity, dry cells' nominal capacity is rated dependent on the profile of discharge. The largest dry cells with the greatest amounts of drawable current are taken into consideration.

Dry cells have a nominal voltage of 1.5 V, while NiCd accumulators only have a value of 1.2 V. This does not concern the interchangeability, as only mean discharge voltage is relevant.

The sealed cell has a more constant voltage than the primary cell under the same load, dropping from 1.3 V to a voltage of 1.0 V at the end of discharge, resulting in a mean discharge voltage of 1.24 V (see Figure 16.7), while dry cells show under maximum exploitation of the capacity a continuous voltage drop to 0.9 V or even 0.75 V, resulting in the mean discharge voltage possibly being even lower than with sealed cells.

Referring to [Figure 16.7](#): Alkaline cells of the mignon (AA resp. R6) size, the most commonly used, have a drawable capacity of about 1200 mAh under a load of 20 mA. The NiCd cell of the same size has only about 200 mAh, which means it has to be recharged three times to yield the same capacity as the alkaline mignon cell. With a life expectancy of around 1000 discharges, the NiCd cell can substitute around 330 alkaline mignon cells. As the price ratio is about 1:10, a significant amount of money can be saved. Additionally, the time factor must of course be recognized in this calculation.

16.10 GUIDELINES FOR USE AND MAINTENANCE

Every owner's manual of any electric battery-powered appliance should contain guidelines for battery changes and the intervals at which to change them.

Naturally a legible short form of manual should be chosen, which must be tailored to fit the appliance. The battery case itself must also contain instructions for size, quality, and the right polarity of the batteries. The following should help to issue these important instructions.

16.10.1 Primary Batteries

Batteries are discharged when the appliance shows variation from normal functions, for instance, when

- Portable radio sets become noticeably fainter and when the sound is distorted when the volume is turned up.
- After short use the power indicators of reel or cassette recorders show “low” or they start wailing.

Other considerations include

- Used-up batteries are to be removed immediately. Deep discharged batteries tend to leak after a short period of time. Also all batteries should be substituted together as there is great danger of leakage of the discharged cells.
- It must always be made certain that the batteries are introduced into the appliance with the right polarity. When in series, operation of cells with one cell inversed may cause rupture. A leakage always follows and the appliance can be severely damaged.
- Batteries of different designs should not be operated together. As the batteries have capacities, some of the cells may get discharged very deeply and leak.
- Dry batteries are not rechargeable as accumulators are. Individuals that offer such charging devices under false pretenses are more than negligent because there is a great danger of explosion!
- The above does not concern the fact, given certain circumstances, that some regeneration of partly discharged cells is possible. These devices are designed in such a way that no damage can be done although no responsibility for this is taken from the manufacturer's side.
- Batteries are leak-proof if these guidelines are followed. In case of leakage as a result of faulty application, the battery chamber and the contacts are to be thoroughly cleaned, preferably with a soft absorbent tissue not to damage the appliance any further.
- Clean contacting surfaces and good contact must be ensured when a new set of batteries is inserted.
- Regard disposal instructions for spent batteries.

16.10.2 VRLA Batteries

- Operation in any position is tolerable.
- For stationary applications the vents shall be on the top or on the side.
- Never open the vents.
- Tolerable temperature for use: 30 to 50 °C.
- Store when not in use in clean and dry (0 to 35 °C) conditions. For charge intervals to compensate self-discharge, see manual.
- Recharge discharged batteries at the latest after one week.
- Charge only with limited voltage: 2.35 V/cell.
- Instructions of the battery manufacturer manual have to be regarded.
- Regard disposal instruction for spent batteries.

16.10.3 NiCd Batteries

When NiCd accumulators are used, the following simple rules must be followed:

- New cells must be charged directly before use with the nominal value I_{10} for 20 to 24 hours.
- After every normal discharge 14 hours of charge with the nominal charging current must be made. Prolonged charging now and then has no effect on the lifespan of a battery.
- When a battery has been completely discharged, for instance when switching off was forgotten, it must be charged with the nominal current I_{10} for 20 to 24 hours.
- Keep contacts of the set clean!
- Whenever the cells are not used for a longer period of time, they must be recharged as quoted above. After two to three recharging cycles, the batteries will have regained their full capacity.
- Regard disposal instructions for spent batteries.

16.10.4 Nickel/Metal Hydride Batteries

- Instructions of the battery manufacture's manual have to be regarded.
- Regard disposal instructions for spent batteries.

16.10.5 Lithium Batteries

- Instructions of the battery manufacturer's manual have to be regarded.
- Regard disposal instructions for spent batteries.

16.11 SUMMARY

The power consumption of an appliance determines the size of the battery, the period of operation, and the operating costs. Only those appliances that incorporate sufficiently dimensioned, safe, and easy-to-use power sources are highly efficient and thus have the best preconditions for being a success.

The process of choosing an electrochemical system as well as the design of the battery must be considered as important tasks and must be carefully accomplished, in which not only technical points of view, but also economic preconditions must be respected.

Because of the multitude of available battery types that can be fitted, which is neither surveyable by the user nor can be judged as to what concerns quality, the appliance's designer must give advice for the best battery system and name economic alternatives for this.

The problem for the designer therefore is as follows:

- The battery must be big enough yet at the same time as small possible; weight and size must be respected.
- Find the technically best solution but also take more economic alternatives into consideration.

- Standardized sizes must be provided as far as possible for good interchangeability for the user. Sets that are frequently used may be alternatively provided with rechargeable batteries.
- Shape must be considered for easy access to the battery case.
- Battery case should be separate from the rest of the appliance so in case of leakage no harm will be done.
- Rugged design and good fit of the contractors should be provided.
- For appliances with accumulators the charging device may be incorporated or the charging socket made easily accessible.
- Mark size and polarity and alternative powering clearly in the battery case.
- Provide legible instruction manuals.

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