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Electrical Engineering Textbook

1st edition

Prepared and revised by teachers at vocational colleges and by engineers
(see next page)

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Dear Reader,

The **Electrical Engineering Textbook** is intended for use in initial and continuing training in the profession of electrical engineering. This first English edition is based on the 29th German edition of the established and reliable textbook “Fachkunde Elektrotechnik.” It is used for the teaching of basic and technical knowledge, in particular in the field of energy technology. It is aimed at everyone who is active in this profession.

Target groups (examples)

- Electronics engineers for energy technology and building technology, automation technology, machine and drive technology, industrial engineering, equipment and systems
- Industrial electricians
- Electric systems technicians
- Electrical engineers
- Students

Structure and use of the book

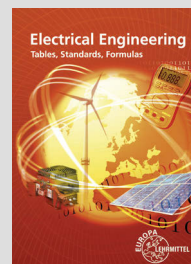
- The book was created by an experienced team of authors made up of teachers, master electricians and engineers.
- It has 17 chapters and is structured systematically according to subjects.
- The book is useful for skills-oriented and practical training.
- It can also be used as a reference work.
- Numerous multi-colored images, tables and charts help with the explanations.
- You will find explanations and uniform representations of important formulas of electrical engineering.
- Formulas and legends form a unit and are highlighted in color inside a frame.
- In the information section, you will find information on electro-technical symbols, characteristics and laying instructions for cables and lines.
- The “Review” pages consolidate and deepen the knowledge you have acquired.
- The results of the calculation tasks from the “Review” can be found on page 631.
- Practical tip pages will be of great support in professional activities.

Note on the standards

The book is based on European and German standards such as DIN, DIN EN, DIN EN ISO and DIN VDE. It is important to note that in some countries other standards, laws and regulations are valid that must be observed.

Auxiliary tool supplementing the Electrical Engineering Textbook

As supplementary technical literature, we recommend for the deepening and completion of your knowledge the book entitled “Electrical Engineering Tables, Standards, Formulas,” also published by Europa-Lehrmittel.



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The team of authors and the publishing house Europa-Lehrmittel

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Subject areas for the first training year in the occupational area of electrical engineering

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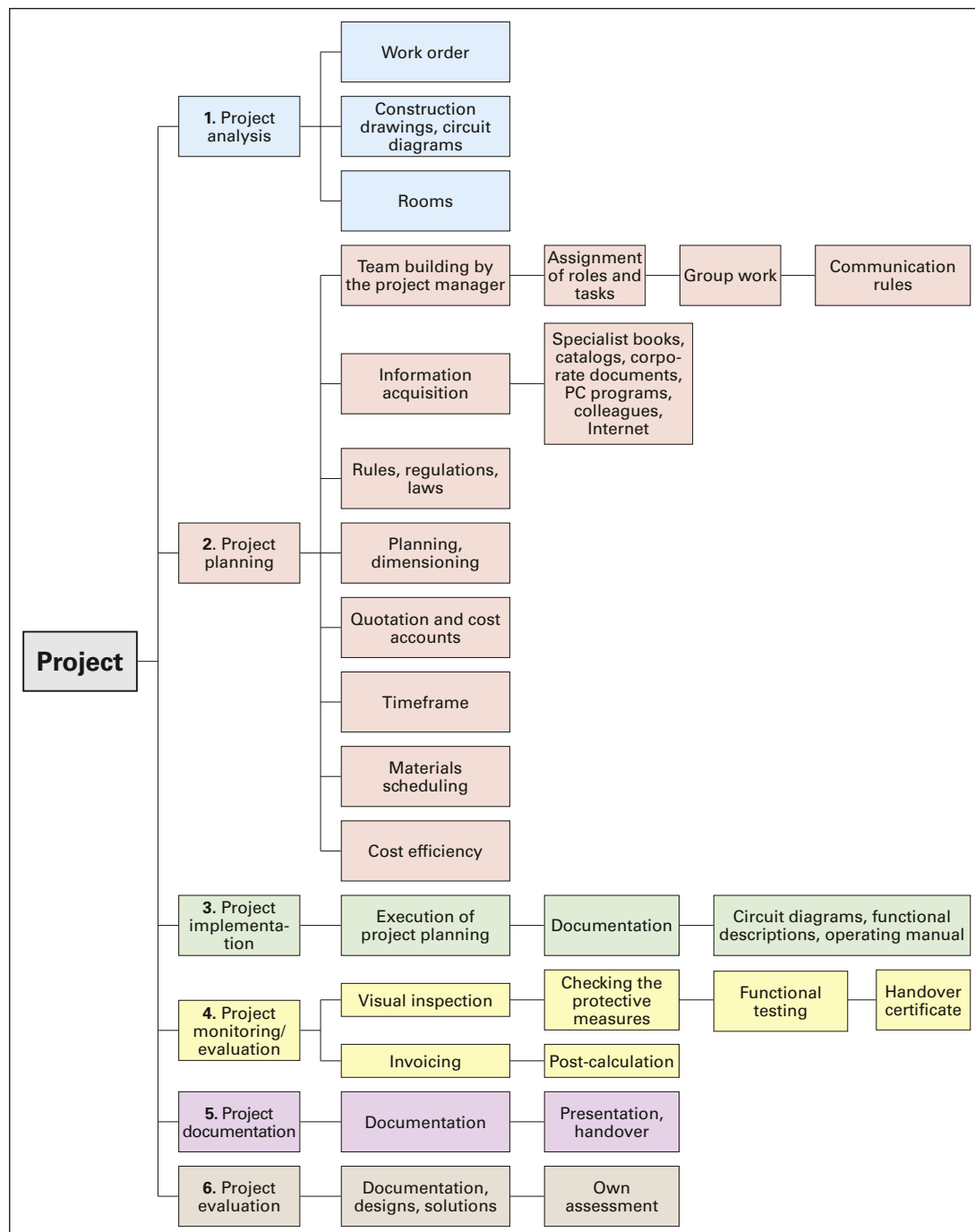
Subject areas 4: Providing information technology systems	
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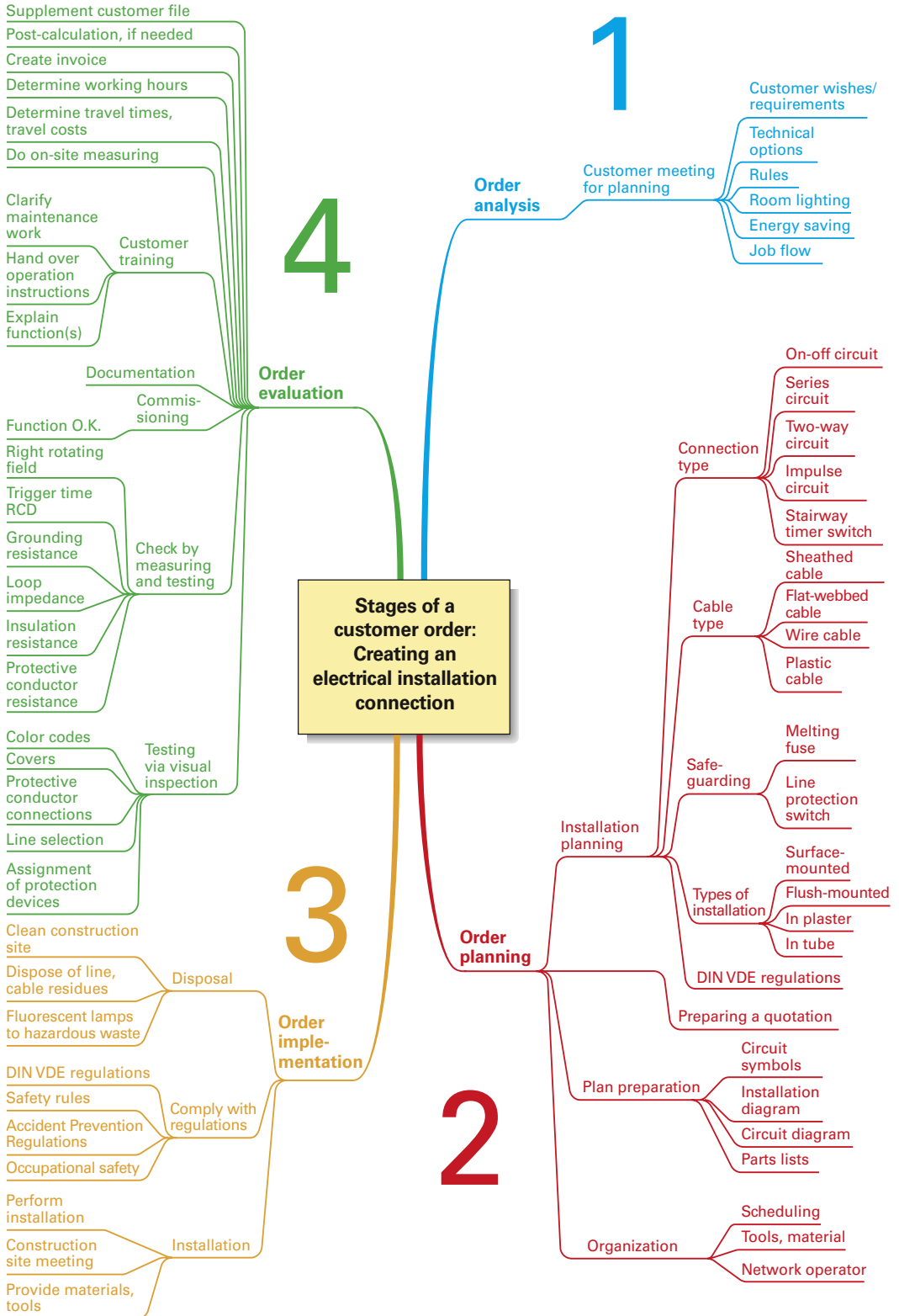
Subject area	Professions *						Content of subject area	Book pages (examples)
	DS	MD	BI	IE	EB	AT		
5	x	x	x	x	x	x	• Supply of electric energy and safety of equipment • Implementing the supply of electric energy for appliances and systems, and ensuring their safety	• Safety in the workplace. 15 • Dangers of electric current 334 • Protective measures 334 • Grid systems 341
6	x	x	x	x	x	x	• Analyzing systems and testing their safety • Analyzing and testing devices and assemblies • Inspecting and testing building services systems • Manufacturing and testing electric machinery • Designing, manufacturing, and testing of electronic components	• Building engineering 371 • Checking the protective measures 356 • Repetitive testing, E check 364, 365 • Electric machinery 449 • Measurement technology 167, 178 • Electronics 192 • Printed circuits 594
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9	x	x	x	x	x	x	• Integrating control and communication systems • Planning and implementing communication systems in residential and functional buildings • Executing and commissioning building technology systems • Integrating systems and awarding third-party services • Repairing electric machinery • Service, inspection and maintenance of devices and systems	• Lines and cables 304 • Line dimensioning 319, 322 • Building engineering 371 • Telecommunications systems 507 • Paging systems 108 • Building services management 422 • Aerial systems 403 • Hazard warning systems 432 • Maintenance and testing of electric machinery 509
10	x	x	x	x	x	x	• Commissioning and handover of automation systems • Commissioning and maintenance of building services systems • Building and maintaining energy systems • Operating building and infrastructure systems according to customer wishes • Selecting and customizing controls and automatic control systems for electric machinery • Setting up manufacturing systems	• Electrical systems engineering 275 • Network systems 289, 341 • Power electronics 243 • Transformers 450 • Automation technology 534 • Electrical appliances 387 • Light and lighting technology 371 • Photovoltaic systems 280 • Automatic control engineering 569 • Lightning protection 440
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12	x	x	x	x	x	x	• Planning automation systems • Planning and implementing energy systems and building services systems • Planning and implementing electrotechnical systems • Planning the changes of use in building and infrastructure systems • Maintenance of drive systems • Planning and implementing appliances and systems	• Electrical systems engineering 275 • Line calculation 322 • KNX 427 • Energy saving 601 • Automation technology 534 • Field buses 563 • Machinery safety 561 • Maintenance and testing of electric machinery 509
13	x	x	x	x	x	x	• Implementing automation systems • Maintenance and changing of energy and building services systems • Maintenance and changing of electrotechnical systems • Optimization of building and infrastructure systems • Adjusting and optimizing drive systems • Maintenance of manufacturing and testing systems	• Protective measures 334 • Checking the protective measures 356 • Selection of an electric motor 482 • Automation technology 534 • Sequence controls 552 • Manufacturing processes 591 • Special types of rooms and systems 323

* Electronics engineer for AT: Automation technology, EB: Energy and building technology, IE: Industrial engineering, BI: Building and infrastructure systems, MD: Machinery and drive technology, DS: Devices and systems, as well as systems electronics engineer (craftsman)

A new project is starting!

A systematic approach is necessary in order to complete projects or orders professionally, e.g. the creation of a circuit installation (**next page**). The **Overview** below shows steps in the processing of a project or an order. They can be translated to any application you wish. Not all project steps are always required. It depends on the job.







1 Occupational safety and health protection ¹⁾

1.1 Safety and health protection in the workplace

Electrical accidents can be largely ascribed to **technical defects**, e.g. missing protective barriers or incorrect insulation. In addition, **organizational shortcomings**, e.g. missing or inadequate work instructions, as well as **human errors**, e.g. faulty actions, can lead to accidents. The **personal protective equipment** at the workplace is of great importance for protection against injury and illness. Personal protective equipment refers to all items (e.g. protective clothing and hardhat) that protect the body against health-endangering effects.

Safeguards and information signs must not be removed, e.g. the sign relating to safety in the workplace (Figure).

The **Ordinance on Industrial Safety and Health (see Overview)** has established directions for the provision and use of work equipment.

Occupational Safety and Health Act. This law has been designed to ensure and improve the safety and health of employees at their workplace, through measures of occupational safety.

The employer is responsible for safety and health protection in the workplace. By law, he is required to conduct a **risk analysis (page 19)** in order to record and assess the specific risks of the work equipment and systems, of the working conditions for the employees, and of the risks to the environment.

Accident Prevention Regulations oblige employers to take measures for the prevention of work accidents, occupational illnesses, and work-related health hazards as well as for effective first aid. The accident prevention regulations issued by trade associations and the public accident insurers are called the **Trade Associations' Regulations for safety and health at work**.

1.2 Product Safety Act

The **Product Safety Act** regulates the requirements for the safety of products as well as their inspection and labeling (e.g. CE label). It applies when products are made available, presented, or used on the market for the first time within the scope of business operations. Products include, for instance, machines, home improvement equipment and household appliances, tools, leisure and sports equipment, all textiles, furniture, toys and personal protective equipment.

¹ The laws referred to in this chapter show the implementation of European Directives in Germany.

Overview: Laws and regulations (examples)

- DIN VDE regulations
- Ordinance on Industrial Safety and Health
- Occupational Safety and Health Act
- Accident Prevention Regulations
- Rules and regulations of the Social Accident Insurance
 - e.g. – Regulation 1 Principles of Prevention
 - Regulation 2 Occupational Physicians and Specialists for Occupational Safety
 - Regulation 3 Electrical Systems and Equipment
 - Regulation 7 Occupational Medical Precautions
- Technical Rules for Operational Safety
- Product Safety Act
- Ordinance on Hazardous Substances

Safety in the workplace

- Work safely and carefully.
- Apply passive safety.
- Wear personal protective equipment.

Look for:

Warning symbols



Mandatory symbols



Prohibitory symbols



Emergency symbols



Fire protection symbols



- Comply with prohibitions, e.g. no drinking, no smoking, no unauthorized entry.
- Report or eliminate safety deficiencies or states of danger immediately.
- Do not use operating equipment, working devices, or work equipment without authorization.
- Maintain tidiness in the workplace.

Through active involvement, keep yourself and colleagues safe from accidents and damage to health.

Figure: Sign relating to safety in the workplace



Definitions of terms from the Product Safety Act

- **Products** are goods, materials and compounds produced by a manufacturing process.
- **Presenting** means the offering, displaying, or demonstrating of products for purposes of advertising or provision on the market.
- **Provision** on the market is any paid or free-of-charge provision of a product for distribution, consumption or use on the market of the European Union (EU) in the course of a commercial operation.



Products reaching the market within the European Union must comply with the safety requirements of the EC Directives. As a sign of compliance, such products bear the **CE¹ label (Figure a)**. The manufacturer thereby declares the compliance (conformity) of the product with the essential safety requirements, and affixes the CE label to the product at his own responsibility.

By affixing the CE label, the manufacturer confirms that the product meets the requirements of EU legislation.

In addition to the CE label, products may also bear the **GS symbol (Figure b)**, meaning that it has been **tested for safety**. The GS symbol is based on the Product Safety Act. Manufacturers may have their products voluntarily tested at testing centers, e.g. TÜV² and VDE³.

Products with the GS symbol ensure that the safety and health of the user is not at risk. Affixing this symbol is allowed only subsequent to a test by the GS test centers.

1.3 Ordinance on Hazardous Substances

The **Ordinance on Hazardous Substances (GefStoffV)** applies to the marketing of substances, mixtures, and products, as well as to the protection of employees and other persons from risks to their health and safety from hazardous substances, and to the protection of the environment from damage caused by substances. Hazardous substances and mixtures, in particular, have to be correctly packaged and labeled. On the basis of a globally harmonized system (GHS⁴), chemical substances are classified and labeled according to identical criteria throughout the world. The GHS system was introduced in the EU in tandem with the CLP⁵ regulation, i.e. the Regulation on Classification, Labeling and Packaging of substances and mixtures. Most notable is the change in the labeling symbols. Instead of the danger symbols, nine hazard pictograms – a red-edged rhombus (diamond) with a black symbol on a white background (**Table**) – are now used. Three pictograms have been added: the gas cylinder, the exclamation point, and the body symbol (human torso and star). For further labeling, the signal words "Caution" and "Hazard" were introduced.

- **Caution:** Signal word indicating less severe hazard categories.
- **Hazard:** Signal word indicating severe hazard categories.

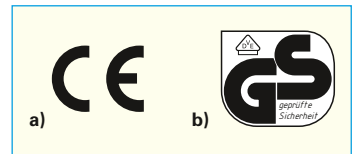


Figure: CE label and GS symbol

Labeling system according to the CLP (GHS) regulation

- Hazard pictogram, e.g.



- **Health hazards** with hazard categories, e.g. acute toxicity, chemical burns, irritation to the skin, gases under pressure.
- **Signal words**
"Caution" or "Hazard"
- **Hazard statements**, (H statements) describe the nature and, if necessary, the severity of the hazard arising from hazardous substances or mixtures (**Figure 1, page 17**).
- **Precautionary statements**, (P-statements) describe the recommended actions to limit or avoid the damaging effects resulting from exposure to a hazardous substance or mixture (**Figure 1, page 17**).

The CLP regulation has been binding for substances since Dec. 1, 2010; for mixtures, it will be binding as of June 1, 2015

Table: Identification of hazards

Physico-chemical hazards				Health hazards				Environmental hazards
Old								
	E	F F+	O	C	T T+	Xi	Xn	N
New								
	Explosive	Flammable	Oxidizing	Corrosive, irritant	Toxic	Irritant	Harmful to health, CMR substances	Harmful to the environment
		Compressed gases	Corrosive substances					

¹ CE, abbreviation for: Communauté Européenne (French) = European Community

² TÜV, abbreviation for "Technischer Überwachungsverein" (Technical Inspection Authority)

³ VDE, abbreviation for "Verband der Elektrotechnik Elektronik Informationstechnik e.V."

(Association for Electrical Engineering, Electronics and Information Technologies)

⁴ GHS, abbreviation for: Globally Harmonized System

⁵ CLP, abbreviation for Classification, Labeling and Packaging



A substance that has been classified and packaged as dangerous has to bear an identification label (Figure 1) with the following elements.



Figure 1: Example of the marking of a dangerous substance

1.4 Safety symbols

Technical guidelines of the Workplace Ordinance describes the requirements for safety and hazard protection marking in workplaces. **Safety symbols** are used for safety and health protection marking. They warn against risks, provide guidance in dangerous situations, and give handling instructions. This also includes the identification of prohibitions. Each symbol has the purpose of calling attention quickly and without ambiguity to objects and situations that can cause hazards.

The combination of **shape** and **safety color** alone indicates immediately whether a symbol is related to information on prohibitory, mandatory action, warning, emergency or fire protection (Table). In addition, safety symbols have a corresponding **icon**.

- **Prohibitory symbols** prohibit any kind of behavior that might cause a hazard, e.g. Do not switch (Figure 2).
- **Mandatory action symbols** prescribe a specific behavior, e.g. Use Hardhat.
- **Warning symbols** warn against risks or hazards, e.g. warning against a laser beam.
- **Emergency symbols** mark escape routes or emergency exits or the route to a first aid facility.
- **Fire protection symbols** identify the locations of fire detection or fire extinguishing facilities.
- **Additional symbols** (Figure 2) may be used only in combination with a safety symbol. They provide additional information by words or texts.

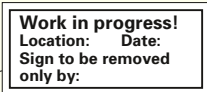
Table: Shape, color, and meaning of safety symbols			
Geometrical shape	Meaning	Safety color	Application example
 Circle with diagonal bar	Prohibition	RED	 No smoking
 Circle	Mandatory action	BLUE	 Use head protection
 Equilateral triangle with rounded corners	Warning	YELLOW	 Warning of flammable substances
 Square	Safeness	GREEN	 Emergency telephone
 Square	Fire protection	RED	 Fire extinguisher
 Prohibitory symbols  Additional symbols			

Figure 2: Prohibitory symbols with additional symbols

1.5 First aid

First aid refers to assistance on the spot, before the injured or sick person is cared for by a doctor.

The life of a wounded person often depends on **first aid (Figure 2)** being administered as quickly as possible directly at the scene of the accident. The employer (contractor) is responsible for effective first aid. He must take the required measures. This includes, in particular, the appointment of a sufficient number of **first aiders**, ensuring appropriate training, and the provision of suitable first aid equipment. In the event of an accident caused by electric current, self-protection must be borne in mind. The current flowing through the victim must be interrupted.

With regard to **low voltage systems** (usual household and industrial voltage, from 230/400 V to a maximum of 1000 V), the interruption of the circuit is performed, for instance, by switching off, pulling out the plug, or removing the fuse. If the circuit cannot be interrupted, the victim must be separated from the live parts by means of a non-conducting object, e.g. an insulated rod.

With **high voltage systems** (1000 V and more, systems marked by the lightning arrow symbol, **Figure 1**), the emergency doctor has to be called immediately, and qualified personnel must be notified. Rescue from high voltage systems is performed solely by qualified personnel. Therefore only competent staff in possession of a switching authorization are allowed to switch off the circuit.

If the **voltage is not known**, as with high voltage systems, a safety distance of at least 5 m has to be maintained. The same measures have to be taken as in the case of high voltage.

Emergency call 112¹

- **Where** did the accident happen?
- **What** happened?
- **How** many are injured?
- **What** injuries?
- **Wait** to answer any questions from the rescue coordination center. Never end the call yourself.

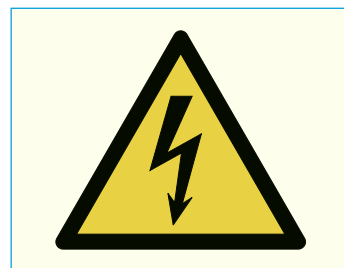


Figure 1: Warning of dangerous voltage

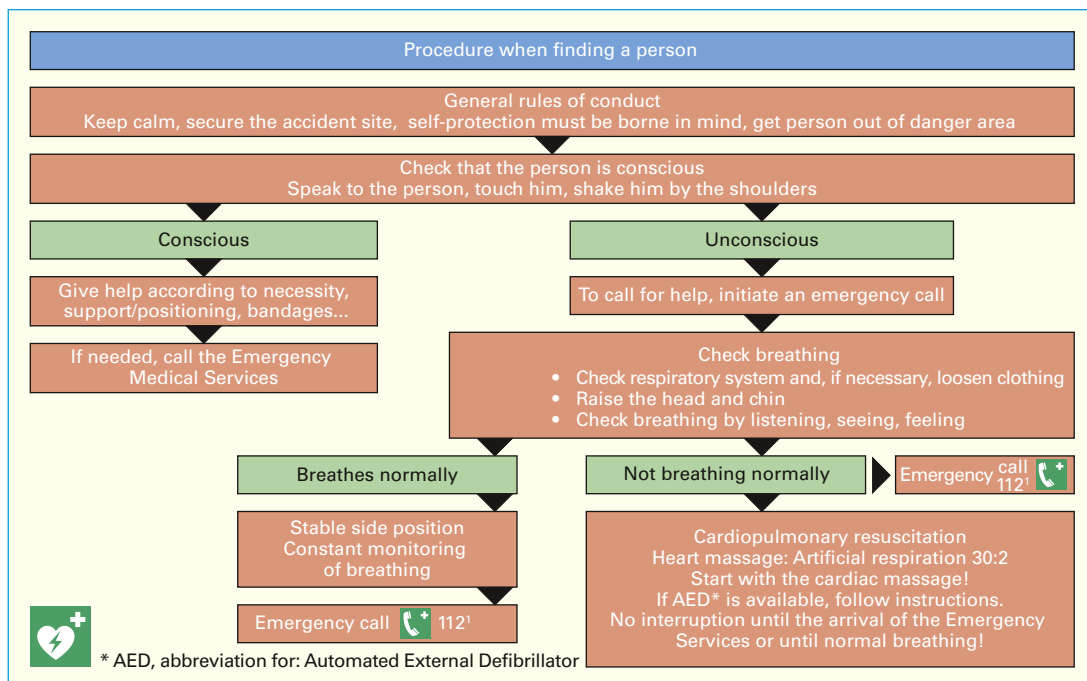


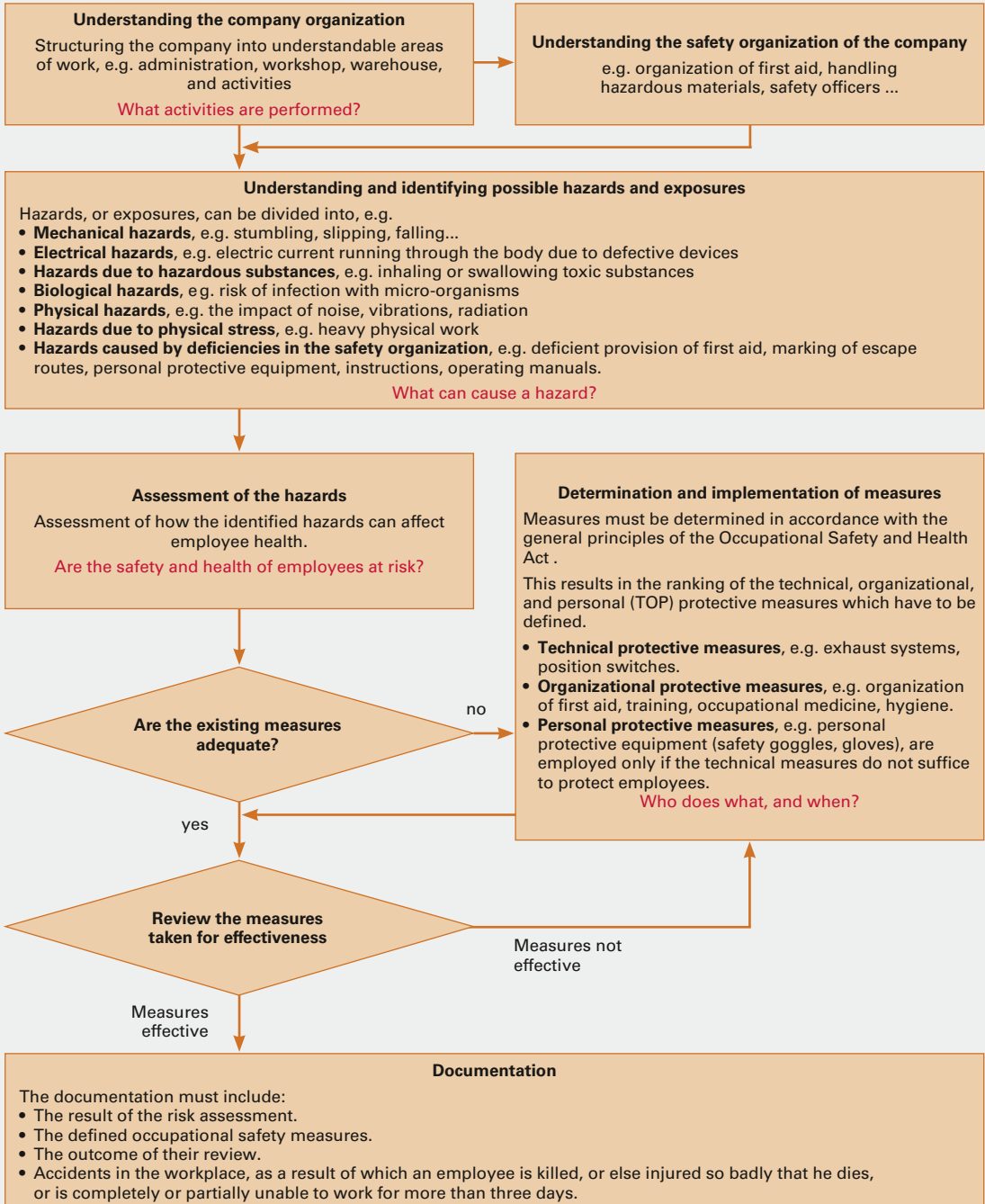
Figure 2: First-aid measures

¹ The European emergency call number is valid in all EU countries, as well as in Iceland, Liechtenstein, Norway and Switzerland



Instructions for conducting a risk assessment

Every activity involves accident risks and health hazards. In order to keep the risks to a minimum, a risk assessment **has to be** performed in workplaces, as per the Occupational Safety and Health Act together with the Ordinance on Industrial Safety and Health. A technical rule for industrial safety describes the basic process of identification and assessment of hazards, and the derivation of appropriate measures.





1. **a)** Which defects or faults usually cause electrical accidents? Name examples. **b)** What are the requirements regarding technical equipment which can be inferred?
2. **a)** What is personal protective equipment? **b)** What is the purpose of personal protective equipment? **c)** Give examples of personal protective equipment.
3. **a)** What is the purpose of conducting a risk assessment? **b)** List the steps to take for the practical implementation of a risk assessment.
4. Which obligations arise for the employer from the Accident Prevention Regulations ?
5. What is the meaning of the following abbreviations: **a)** CLP, **b)** GHS?
6. What do the **a)** CE label and **b)** GS symbol on products mean?
7. Which regulation is designed to protect workers against risks to their health from hazardous substances?
8. Name the designations for the hazard pictograms shown in **Figure 1** from **a)** to **g)**.



Figure 1: Hazard pictograms

9. Which information has to be present on the packaging of hazardous substances?
10. What is the assessment called by means of which accident and health risks in workplaces are kept as low as possible?
11. What are the obligations arising for companies from the Accident Prevention Regulation "Safety and Health Protection Labeling at the Workplace"?
12. What are the prerequisites for allowing products to be brought onto the market, and by means of which symbol is this indicated?

13. What are the two characteristics that distinguish safety symbols?
14. Name safety colors **a)** to **d)** for the safety symbols specified in the **Table**.

Table: Shape and safety colors of safety symbols

Safety color \ Shape	a)	b)	c)	d)
Circle	Prohibition	—	Mandatory action	—
Triangle	—	—	—	Warning
Square	Fire protection	Safeness	—	—

15. **a)** Which safety symbols can be distinguished, and **b)** which information can be learned from the respective symbols?
16. Name the safety symbols depicted in **Figure 2**, and describe their meaning.

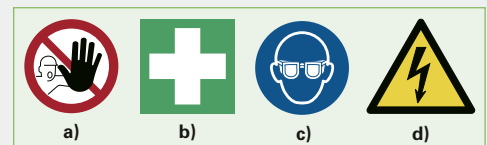


Figure 2: Safety symbols

17. Why are additional symbols frequently used together with safety symbols?
18. What information is it imperative to provide in an emergency call?
19. What is first aid?
20. What are the immediate measures to be taken in the event of accidents caused by electric current?
21. How can you help someone who has suffered an accident caused by electric current if the circuit cannot be interrupted?
22. Describe the first aid measures when you come upon an injured person who is **a)** responsive or **b)** non-responsive.