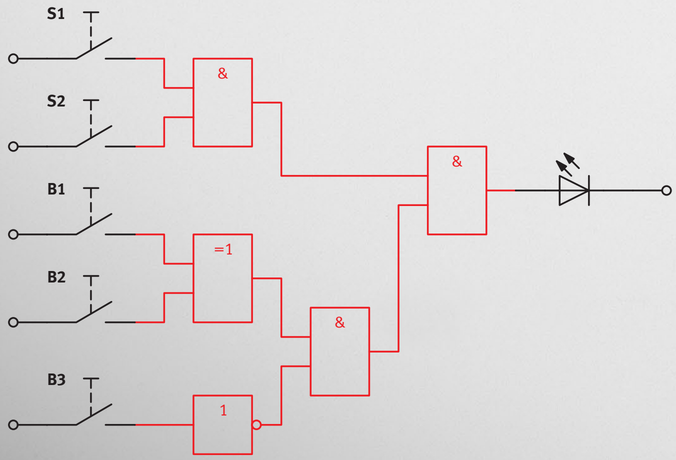
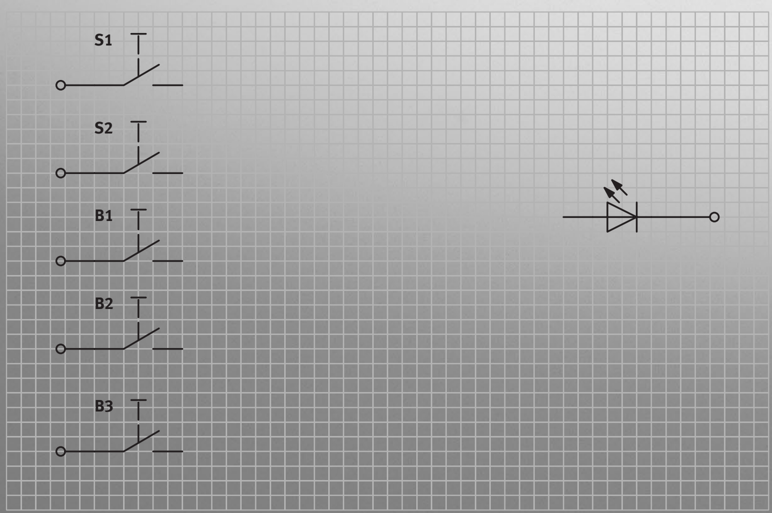
Basic principles of digital technology





FESTO

Workbook
TP 1012

With CD-ROM

Festo Didactic
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Edition: 10/2013
Author: Stefan Enderle
Editor: Frank Ebel
Graphics: Susanne Durz, Stefan Enderle, Doris Schwarzenberger
Layout: 11/2013, Frank Ebel

Internet: www.festo-didactic.com
E-mail: did@de.festo.com

Table of contents

Exercises and solution sheets

Exercises and worksheets

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Use for intended purpose

The training package “Basic principles of digital technology” may only be used:

- For its intended purpose in teaching and training applications
- When its safety functions are in flawless condition

The components included in the training package are designed in accordance with the latest technology as well as recognised safety rules. However, life and limb of the user and third parties may be endangered, and the components may be impaired, if they are used incorrectly.

The training system from Festo Didactic has been developed and manufactured exclusively for training and continuing vocational education in the field of automation technology. The training companies and/or trainers must ensure that all trainees observe the safety instructions included in this workbook.

Festo Didactic hereby excludes any and all liability for damages suffered by trainees, the training company and/or any third parties, which occur during use of the equipment sets in situations which serve any purpose other than training and/or vocational education, unless such damages have been caused by Festo Didactic due to malicious intent or gross negligence.

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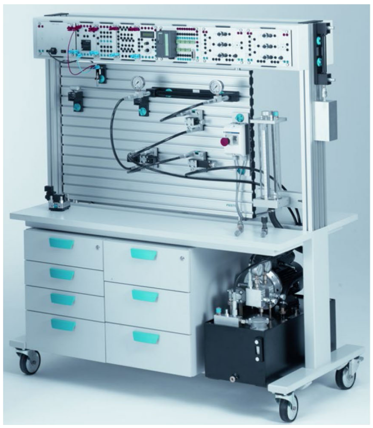
Preface

Festo Didactic’s training system for automation and technology is geared towards various educational backgrounds and vocational requirements. The training system is therefore broken down as follows:

- Technology-oriented training packages
- Mechatronics and factory automation
- Process automation and control technology
- Mobile robotics
- Hybrid learning factories

The training system for automation and technology is continuously updated and expanded in accordance with developments in the field of education, as well as actual professional practice.

The technology packages deal with various technologies including pneumatics, electro-pneumatics, hydraulics, electro-hydraulics, proportional hydraulics, programmable logic controllers, sensor technology, electrical engineering, electronics and electric drives.



The modular design of the training system allows applications which go above and beyond the limitations of the individual training packages. For example, PLC actuation of pneumatic, hydraulic and electric drives is possible.

All training packages feature the following elements:

- Hardware
- Media
- Seminars

Hardware
The hardware in the training packages is comprised of industrial components and systems that are specially designed for training purposes. The components contained in the training packages are specifically designed and selected for the projects in the accompanying media.

Media
The media provided for the individual topics consist of a mixture of teachware and software. The teachware includes:

- Technical literature and technical books (standard works for teaching basic knowledge)
- Workbooks (practical exercises with supplementary instructions and sample solutions)
- Lexicons, manuals and technical books (which provide technical information on groups of topics for further exploration)
- Transparencies and videos (for easy-to-follow, dynamic instruction)
- Posters (for presenting information in a clear-cut way)

Within the software, the following programmes are available:

- Digital training programmes (learning content specifically designed for virtual training)
- Simulation software
- Visualisation software
- Software for acquiring measurement data
- Project engineering and design engineering software
- Programming software for programmable logic controllers

The teaching and learning media are available in several languages. They are intended for use in classroom instruction, but are also suitable for self-study.

Seminars
A wide range of seminars covering the contents of the training packages round out the system for training and vocational education.

Do you have feedback about this manual?

If so, send us an e-mail at did@de.festo.com.
The authors and Festo Didactic look forward to your comments.

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Work and safety instructions

General information
- Trainees should only work with the circuits under the supervision of a trainer.
- Observe specifications included in the technical data for the individual components, and in particular all safety instructions!
- Malfunctions which may impair safety must not be generated in the training environment, and must be eliminated immediately.

Electrical functions
- **Risk of death in case of interrupted protective earth conductor!**
  - The protective earth conductor (yellow/green) must never be interrupted, either inside or outside of a device.
  - The insulation of the protective earth conductor must never be damaged or removed.
- In schools and training facilities, the operation of power supply units must be responsibly monitored by trained personnel.
- **Caution!**
  The capacitors in the device may still carry a charge even after it has been disconnected from all power sources.
- When replacing fuses, use specified fuses only with the correct current rating.
- Never switch the power supply unit on immediately after it has been moved from a cold room to a warm room. Under unfavourable conditions, the condensate which forms as a result may damage the device. Leave the device switched off until it has reached room temperature.
- Use only extra-low voltage (max. +5 V DC) as operating voltage for the circuits in the various exercises.
- Electrical connections may only be established in the absence of voltage.
- Electrical connections may only be interrupted in the absence of voltage.
- Use only connecting cables with safety plugs for electrical connections.
- Pull the plug only when disconnecting connector cables – never pull the cable.

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Training package “Basic principles of digital technology” (TP 1012)

The training package TP 1012 consists of a multitude of individual training materials. The subject of training package TP 1012 is the basic principles of digital technology. Individual components from training package TP 1012 may also be included in other packages.

Important components of TP 1012

- Permanent workstation with EduTrainer® universal patch panel
- Digital technology component set and laboratory safety cables
- EduTrainer® Combiboard for digital and closed-loop control technology
- Complete set of laboratory equipment

Media

The teachware for training package TP 1012 consists of technical books, a book of tables and a workbook. The technical books explain the basic principles of digital technology in a clearly structured and easy-to-follow way. The workbook includes exercise sheets for each exercise, the solutions to each individual worksheet and a CD-ROM. A set of ready-to-use exercise sheets and worksheets is included in the workbook for all of the exercises.

Data sheets for the hardware components are made available along with the training package, and on the CD-ROM.

Media	
Technical books	Technical knowledge for the electrical professions Electrical engineering
Book of tables	Electrical engineering/electronics
Workbook	Basic principles of digital technology

Overview of media for training package TP 1012

The media are offered in several languages. Further training materials can be found in our catalogues and on the Internet.

Allocation of learning objectives to exercises – Basic principles of digital technology

Exercise 1: Familiarisation with elementary logic modules
- You become familiar with the most commonly used logic operators.
- You become familiar with the most important symbols.
- You learn to implement simple logic statements as circuits.

Exercise 2: Designing and optimising logic circuits
- You become familiar with the most important laws of Boolean algebra.
- You become familiar with the terms conjunctive and disjunctive normal form.
- You learn to use switching matrix diagrams in order to simplify circuits.

Exercise 3: Using a Schmitt trigger
- You become familiar with the Schmitt trigger component.
- You learn what hysteresis is.
- You learn to debounce pushbuttons.
- You learn to precisely identify noisy digital data.

Exercise 4: Using trigger circuits
- You become familiar with different types of trigger circuits.
- You learn the significance of the range of applications of the components.
- You learn how to integrate delay elements into digital circuits.

Exercise 5: Using flip-flops
- You become familiar with the different types of flip-flops.
- You learn the significance of the range of applications of the components.
- You learn how to set up digital circuits with "memory".

Exercise 6: Developing counting circuits
- You become familiar with synchronous and asynchronous counting circuits.
- You learn how to implement a frequency divider.
- You learn to develop forward and backward counting circuits.
- You learn to "program" counters.

Exercise 7: Converting and transmitting data
- You become familiar with various types of shift registers.
- You learn to convert serial into parallel data flow, and vice versa.

Exercise 8: Setting up arithmetic circuits
- You become familiar with various adding circuits.

Equipment set

The workbook for basic principles of digital technology imparts knowledge regarding the layout, function and performance of circuits with digital modules.

The set of components for the basic principles of digital technology (TP 1012) includes all of the modules required to achieve the specified learning objectives. Digital multimeters and safety laboratory cables are also required for setting up and evaluating functioning circuits.

Set of components for basic principles of digital technology

Component	Order no.	Quantity
Inverter / Schmitt trigger	760282	1
AND with 2 inputs	760283	1
OR with 2 inputs	760284	1
NAND with 2 inputs	760285	1
NOR with 2 inputs	760286	1
XOR with 2 inputs	760287	1
AND with 4 inputs	760288	1
OR with 4 inputs	760289	1
LED bar graph with 10 digits	760290	1
Counter, 4 bit	760291	1
7-segment display	760292	1
RS flip-flop	760293	1
JK flip-flop	760294	2
Shift register, 8 bit, parallel-serial	760295	1
Shift register, 8 bit, serial-parallel	760296	1
Full adder, 4 bit	760297	1
4-off control switch / pushbutton, single pushbutton	760298	1
2-off hex switch	760299	1

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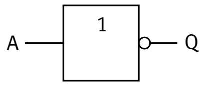
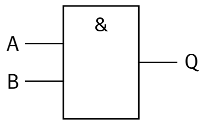
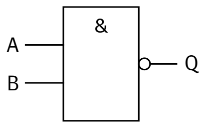
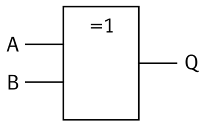
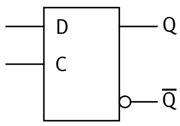
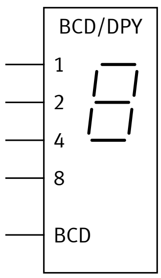
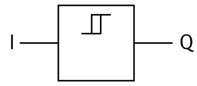
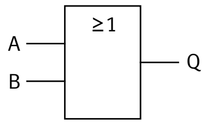
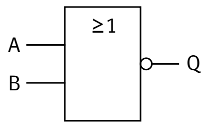
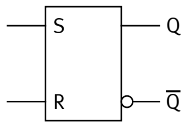
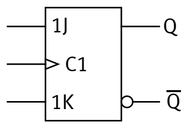
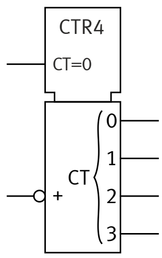
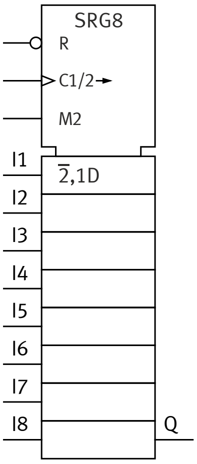
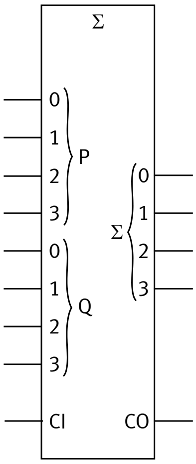
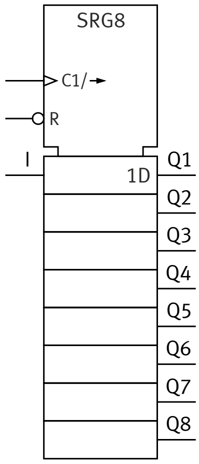
Graphic symbols for the components

Component	Graphic symbol
Inverter	
AND with 2 inputs	
NAND with 2 inputs	
XOR with 2 inputs	
D flip-flop	
7-segment display	

Component	Graphic symbol
Schmitt trigger	
OR with 2 inputs	
NOR with 2 inputs	
RS flip-flop	
JK flip-flop	
Counter, 4 bit	

Component	Graphic symbol
Shift register, 8 bit, parallel-serial	
Full adder, 4 bit	
Shift register, 8 bit, serial-parallel	

Allocation of components and exercises – Basic principles of digital technology

Component \ Exercise	1	2	3	4	5	6	7	8
Inverter	1	3	1	1	2	4		1
Schmitt trigger			1	1				
AND with 2 inputs	3	2		1	3	4		2
OR with 2 inputs	3	2				1		1
NAND with 2 inputs	3				4	2		
NOR with 2 inputs	1				2	1		
XOR with 2 inputs	1	1						2
AND with 4 inputs		3				1		
OR with 4 inputs		4			1			
LED bar graph with 10 digits	1	1	1	1	1	1	1	1
Counter, 4 bit			1	1				
7-segment display			1		1	1		
RS flip-flop					4			
JK flip-flop					1	4	4	
Shift register, 8 bit, parallel-serial							1	
Shift register, 8 bit, serial-parallel							1	
Full adder, 4 bit								1
4-off control switch / pushbutton, single pushbutton	1	1		1	1	1	1	1
2-off hex switch			1	1				1

Notes for the teacher/trainer

Learning objectives
The basic learning objective of this workbook is the setup and analysis of selected basic circuits in the field of digital technology. The contents include elementary logic modules and logic circuits, Schmitt triggers, trigger circuits, flip-flops, counting circuits, data conversion and arithmetic circuits.

Required time
The time required for working through the exercises depends on the learner's previous knowledge of the subject matter. Roughly 1 to 1½ hours should be scheduled for each exercise.

Equipment set components
The workbook and the equipment set are designed to be used together. All 8 exercises can be completed using components from one TP 1012 equipment set.

Standards
The following standards are used in this workbook:

EN 60617-2 to EN 60617-13	Graphic symbols for diagrams
EN 81346-2	Industrial systems, installations and equipment and industrial products; structuring principles and reference designations
IEC 60364-1	Low-voltage electrical installations – Fundamental principles, Assessment of general characteristics, definitions
IEC 60346-4-41	Low-voltage electrical installations – Protective measures – Protection against electric shock

Identification in the workbook
Solutions and supplements in graphics or diagrams appear in red.
Exception: Information and evaluations regarding current are always in red; information and evaluations regarding voltage are always in blue.

Identification in the worksheets
Texts which require completion are identified with a grid or grey table cells.
Graphics and diagrams which require completion include a grid.

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Solutions
The solutions specified in this workbook are the result of test measurements. The results of your measurements may deviate from these.

Learning topics
For the profession of electronics technician, the learning topic "basic principles of digital technology" is part of learning field 1 at vocational colleges.

Structure of the exercises

All 8 exercises have the same structure and are broken down into:
- Title
- Learning objectives
- Description of the problem
- Circuit or layout
- Work assignment
- Work aids
- Worksheets

The workbook contains the solutions to each worksheet included in the exercise book.

Component designations

The components in the circuit diagrams are identified in accordance with EN 81346-2. Letters are assigned as appropriate to each component. Multiple components of the same type within a single circuit are numbered.

Resistors:	-R, -R1, -R2, ...
Capacitors:	-C, -C1, -C2, ...
Indicators:	-P, -P1, -P2, ...

> **Note**
> If resistors and capacitors are interpreted as physical variables, the letter identifying them is in italics (symbols). If digits are required for numbering, they are treated as indices and appear as subscript.

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Contents of the CD-ROM

The workbook is included on the CD-ROM as a PDF file. The CD-ROM also provides you with additional media.

The CD-ROM contains the following folders:
- Operating instructions
- Illustrations
- Presentations
- Product information

Operating instructions
Operating instructions are provided for various components included in the training package. These instructions are helpful when using and commissioning the components.

Illustrations
Photos and graphics of components and practical applications are made available. These can be used to illustrate individual tasks or to supplement project presentations.

Presentations
This directory contains short presentations for the circuits covered by the training package. These can be used, for example, to create project presentations.

Product information
Contains product information from the manufacturers of selected components. The representations and descriptions of the components in this format are intended to show how they would appear in an industrial catalogue. Additional information regarding the components is also included.

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Contents

Exercises and solutions

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Exercise 1

Using elementary logic modules

Learning objectives

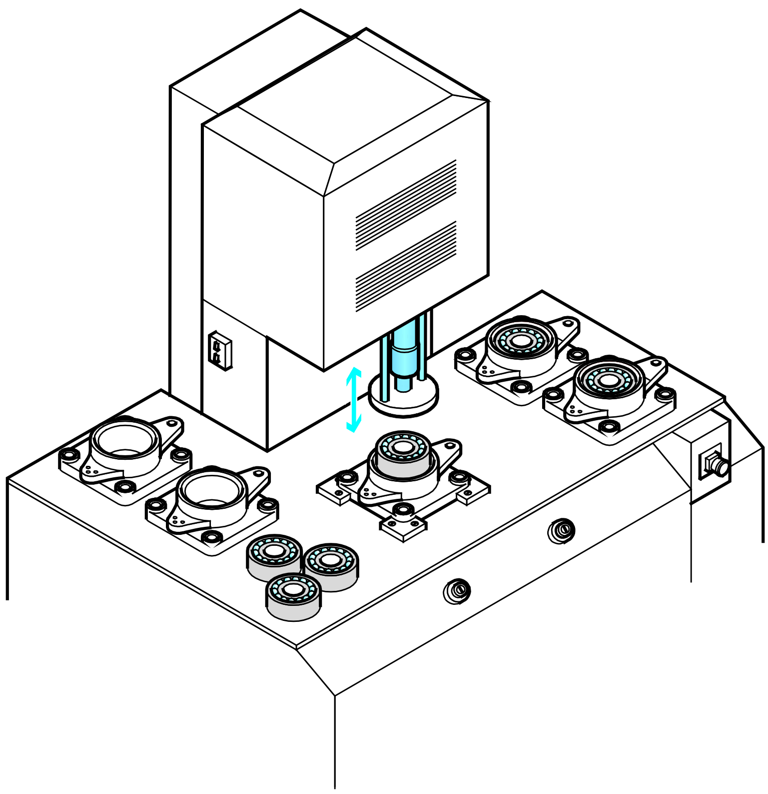
After completing this exercise:

- You'll be familiar with the most commonly used logic operators.
- You'll be familiar with the most important symbols.
- You'll be able to implement simple logic statements as circuits.

Problem description

A hydraulic press in a production facility is initially loaded with raw material, and then the pressing operation is triggered. Both tasks are executed by one person. In order to ensure the safety of the operator, he must only be able to activate the press when with each of his hands he presses a separate start button and the material is detected by either sensor 1 or sensor 2. As an additional safeguard, a check is carried out to determine whether or not the integrated light barrier is interrupted.

Layout



Hydraulic press

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Work assignments

1. Research the term “binary states”.
2. Familiarise yourself with the different ways of representing logic operations.
3. Examine the NOT operation.
4. Examine the AND operation.
5. Examine the OR operation.
6. Examine the NAND operation.
7. Examine the NOR operation.
8. Examine the XOR operation.
9. Examine logic operations with more than two inputs.
10. Set up the circuit for controlling the hydraulic press.

Work aids

- Technical books
- Books of tables
- Operating instructions
- Data sheets
- Internet

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1. Binary states

Information – binary states

Only two different voltage levels are used in the field of digital technology:

- High voltage
- Low voltage

Which voltage values are actually used for the two different levels depends on how the integrated circuits (ICs) used are implemented. In the case of typical transistor-transistor logic modules (TTL modules), high and low levels are 5 V and 0 V respectively (a voltage of 3.3 V is often used for high level at the moment).

In order to designate the voltage levels in abstract terms, the two logic states are usually called simply high and low, or the abbreviations 1 and 0 are used.

Common designations for binary states		
Logic designation	True	False
Voltage level, German	Hoch	Niedrig
Voltage level, English	High	Low
Binary format	1	0
Implementation	High voltage	Low voltage

– Type 74HCxx logic ICs are used in the set of components for “digital technology”.
Ascertain maximum low and high levels at the inputs and outputs for this series of ICs with a supply voltage of 4.5 V and 6 V. Enter the values in the table.

	Input		**Output**	
Supply voltage	**Low V_{IL}**	**High V_{IH}**	**Low V_{OL}**	**High V_{OH}**
4.5 V	1.35 V	3.15 V	0.33 V	3.84 V
6 V	1.8 V	4.2 V	0.4 V	5.34 V

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2. Ways of representing logic operations

Information – logic operations

In digital circuits, several binary inputs are usually linked to a single output. For example, if a machine is only set into motion when pushbutton A as well as pushbutton B are pressed, we speak of an AND operation. If it's only necessary to press one of the pushbuttons, we're dealing with an OR operation.

The electronic modules by means of which logic operations are implemented are also called logic gates, or simply gates.

There are different ways in which logical relationships between several input signals and the associated output signal can be clearly represented; these are shown below.

- **Truth table**
  The relationship between the input and the output of a logic operation is represented in text form in a value table (or truth table). There's a row for each possible input assignment combination which describes the corresponding inputs signals and the associated output signal.

Input A	Input B	Output
Low	Low	Low
Low	High	Low
High	Low	Low
High	High	High

Truth table (comprehensive)

The following format is shorter, where variables A and B are used for the inputs and Q is used for the output. The logic levels are designated merely as 1 and 0.

A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

Truth table (condensed)

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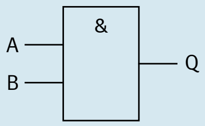
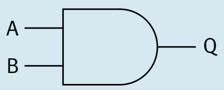
- **Operation equation**
  An operation equation can be used to represent a logic operation in an even more compact fashion than would be possible with a truth table. The relationship between the input and output signals is described by a mathematical equation in this case:

  Examples:
  – Q = A **AND** B
  – Q = A **OR** B
  – Q = **NOT** A **AND NOT** B

  In the following sections you'll learn the mathematical symbols for the **AND**, **OR** and **NOT** operations.

- **Circuit symbol**
  There are special symbols for the basic logic functions in order to be able to create digital circuits in the usual way in the form of circuit diagrams. The following table shows various symbols for the AND operation depending on which standard is used:

International standard **EN 60617-12**	**American standard** **ANSI 91-1984**
	

Circuit symbols for AND operations

Note
Only symbols in accordance with EN 60617-12 will be used on the following pages.

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3. NOT operation, inverter

Information – NOT operation

The simplest logic operation – with just one input signal and one output signal – is the NOT operation which is usually known as an inverter. The inverter turns the signal of the logic level around and thus generates a low level at the output from a high level at the input, or vice versa.

- **Truth table**
  The truth table for the NOT operation is very simple, because input variable A has only two possible assignments.

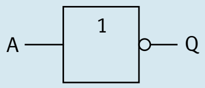
C	Q
0	1
1	0

Truth table for the NOT operation

- **Operation equation**
  The inverted signal is identified by means of a horizontal line above the corresponding input variable:

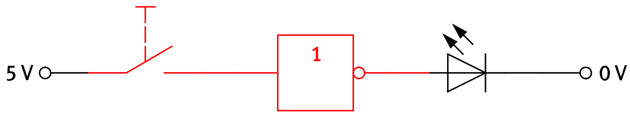
  NOT operation $Q = \overline{A}$

- **Circuit symbol**
  The following symbol is used for the inverter in a digital circuit (circuit diagram):

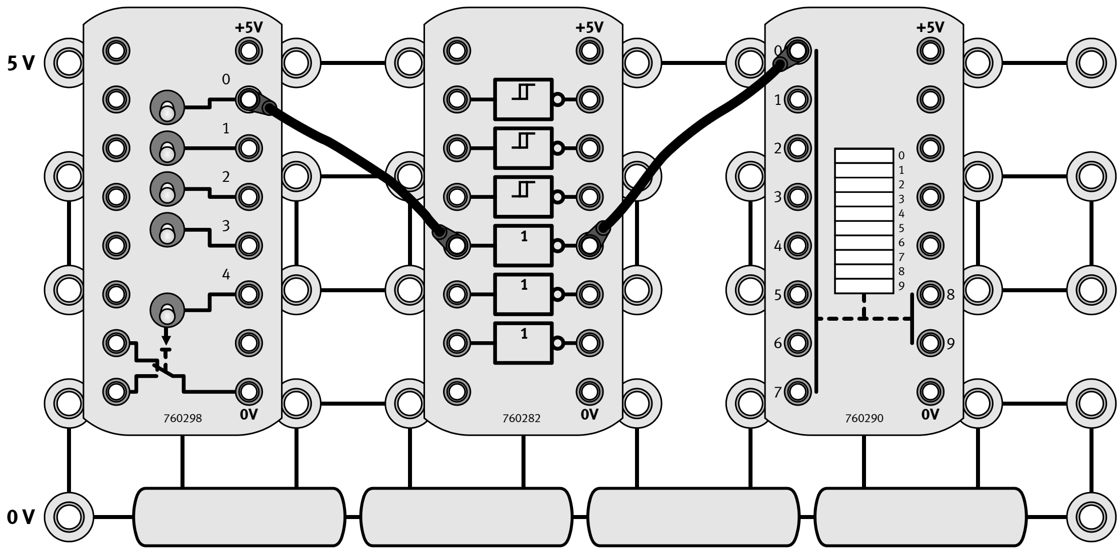


Circuit symbol for the NOT operation

a) Sketch a circuit with a pushbutton, an inverter and an LED. The LED should light up precisely when the pushbutton is not pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbutton 0
Inverter / Schmitt trigger	1 inverter
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

4. AND operation

Information – AND operation

As opposed to the inverter, the AND operation has two inputs which control the level of the output. The output level is only high when a high level is applied to both inputs.

- **Truth table**
  The truth table for the AND operation has four rows, because both input variables, A and B, have two possible assignments. Precisely when high potential is applied to both inputs, high potential is also read out at the output.

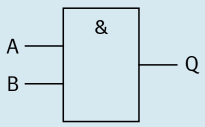
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

Truth table for the AND operation

- **Operation equation**
  The AND operation for two variables, A and B, is represented by a triangle open at the bottom between the variables:

  AND operation: $Q = A \wedge B$

- **Circuit symbol**
  The circuit symbol indicates the logic operation by means of an ampersand (&):



Circuit symbol for the AND operation

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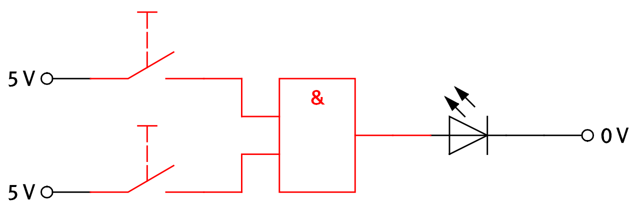
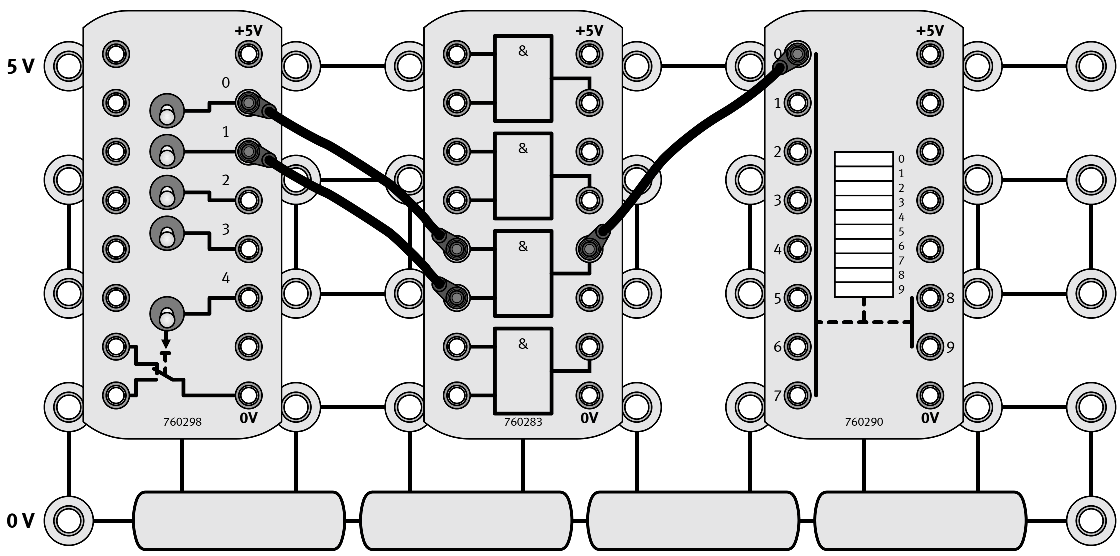
a) Sketch a circuit with two pushbuttons, one AND gate and one LED. The LED should light up precisely when both pushbuttons are pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
AND with 2 inputs	1 AND
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

5. OR operation

Information – OR operation

The OR operation is analogous to the AND operation, but in this case the output level is high whenever a high level is applied to at least one input.

- **Truth table**
  Like the AND operation, the OR operation has four possible input assignments. High potential is always read out at the output when at least one of the inputs is high.

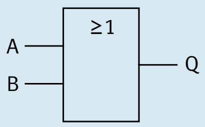
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

Truth table for the OR operation

- **Operation equation**
  The OR operation for two variables, A and B, is represented by a triangle open at the top between the variables:

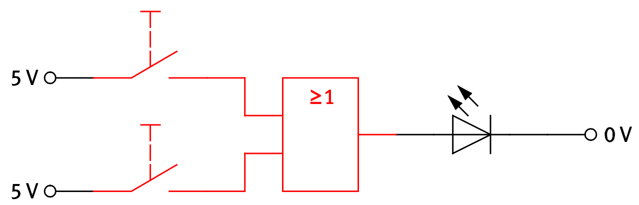
  OR operation: $Q = A \vee B$

- **Circuit symbol**

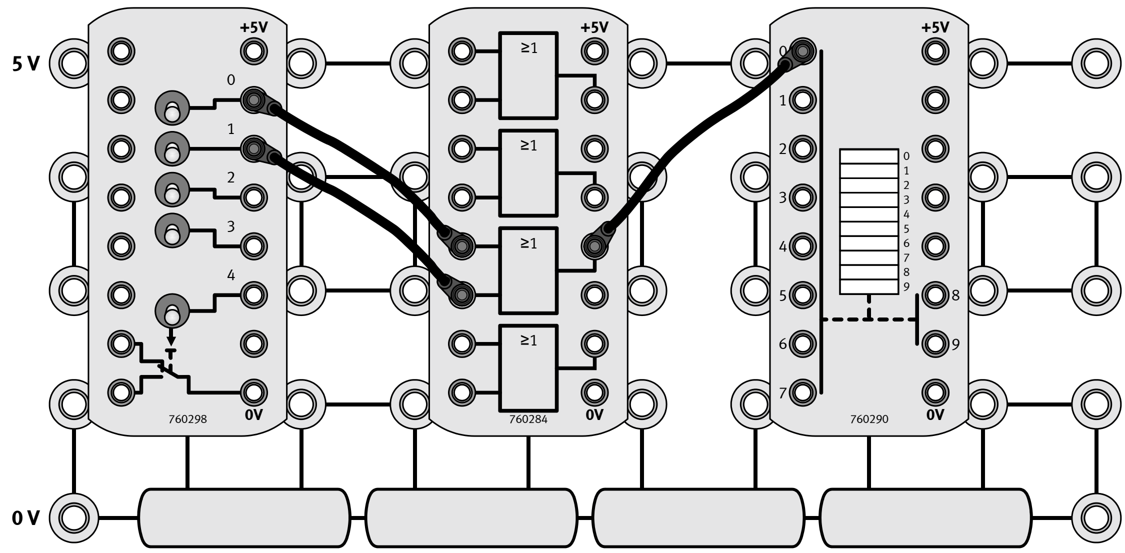


Circuit symbol for the OR operation

a) Sketch a circuit with two pushbuttons, one OR gate and one LED. The LED should light up as soon as at least one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
OR with 2 inputs	1 OR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

6. NAND operation

Information – NAND operation

In addition to the basic functions described thus far, the negated forms of the AND and OR operations are also used frequently. Within this context, negated (or inverted) means that the actual output level is reversed by means of a NOT gate.

- **Truth table**
  A comparison with the truth table for the AND operation reveals that the NAND operation delivers precisely the opposite output signal.

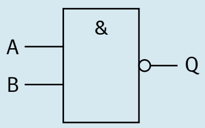
A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

Truth table for the NAND operation

- **Operation equation**
  The same symbol is used in the operation equation as is also the case for the AND operation. However, the negation line which appears above the entire equation indicates the final inverting step.

  NAND operation: $Q = \overline{A \wedge B}$

- **Circuit symbol**



Circuit symbol for the NAND operation

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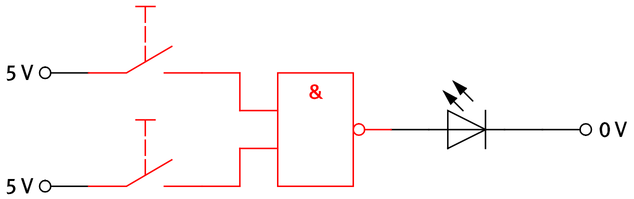
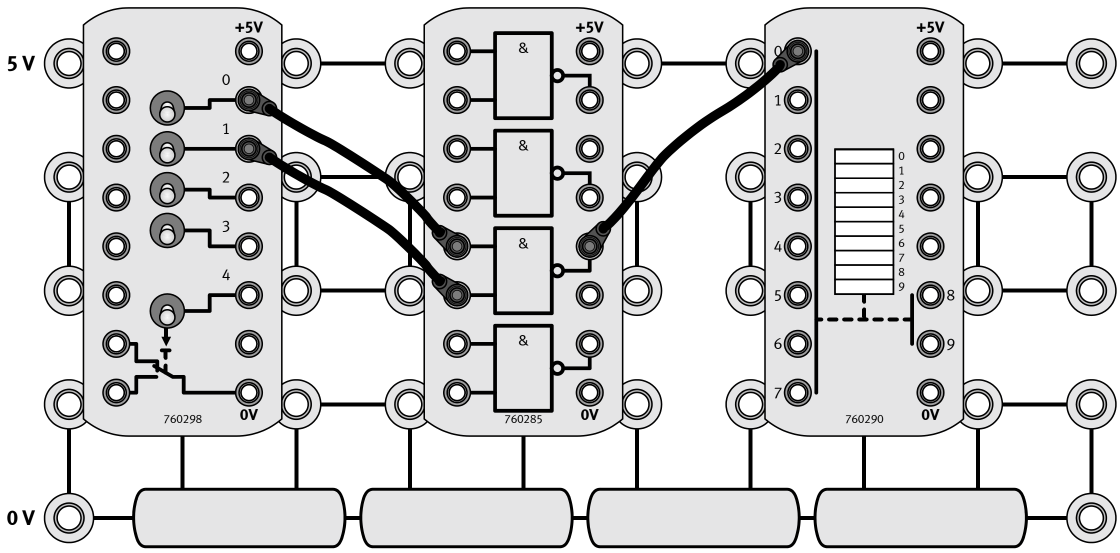
a) Sketch a circuit with two pushbuttons, one NAND gate and one LED. The LED should go out precisely when both pushbuttons are pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit for to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
NAND with 2 inputs	1 NAND
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

7. NOR operation

Information – NOR operation

Analogous to the NAND operation, the NOR operation results from an OR operation with a subsequent NOT gate.

- **Truth table**
  The NOR operation results in a high level output precisely when both input signals are at low level.

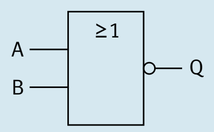
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

Truth table for the NOR operation

- **Operation equation**
  The operation equation shows the OR operation for A and B followed by the negation of the entire equation.

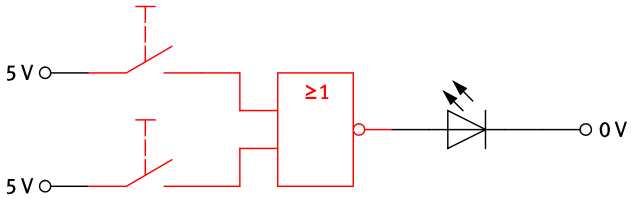
  NOR operation: $Q = \overline{A \vee B}$

- **Circuit symbol**

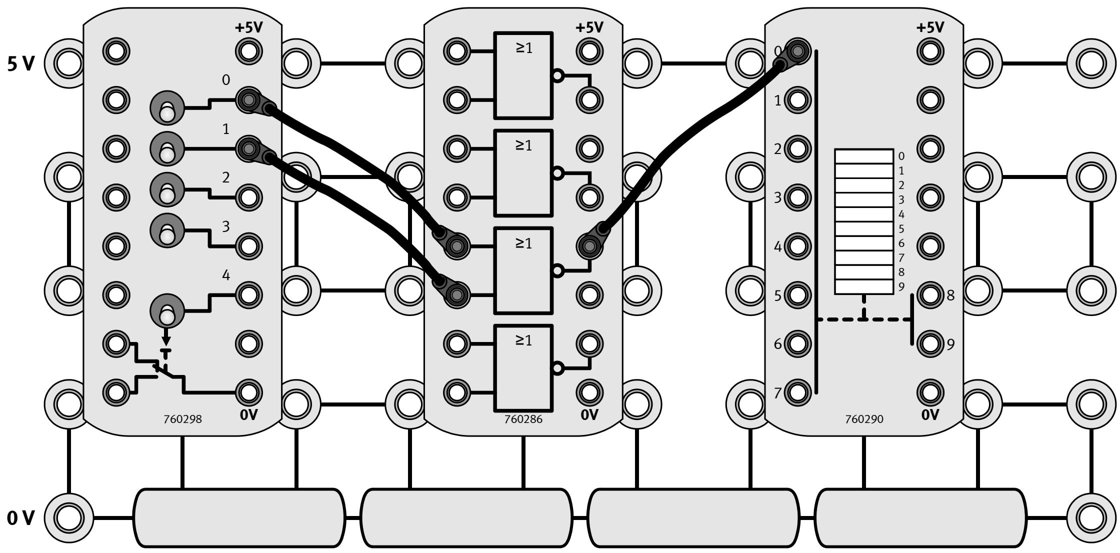


Circuit symbol for the NOR operation

a) Sketch a circuit with two pushbuttons, one NOR gate and one LED. The LED should go out as soon as at least one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
NOR with 2 inputs	1 NOR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

8. XOR operation (eXclusive OR)

Information – XOR operation

In the case of the so-called XOR operation, the output is high precisely when a high level is applied to one or the other input. If the same level is applied to both inputs, the output is low. And thus the XOR operation corresponds to the OR operation, except that a high output level only occurs when exclusively one input is high, thus resulting in the name "exclusive or".

- **Truth table**
  The XOR operation results in a high level output precisely when one of the two input signals is at a high level.

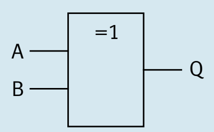
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

Truth table for the XOR operation

- **Operation equation**
  The XOR operation for A and B is made apparent in the operation equation by the operator, which consists of a circle with a cross.

  XOR operation: $Q = A \oplus B$

- **Circuit symbol**



Circuit symbol for the XOR operation

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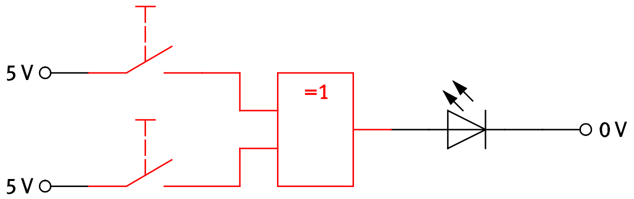
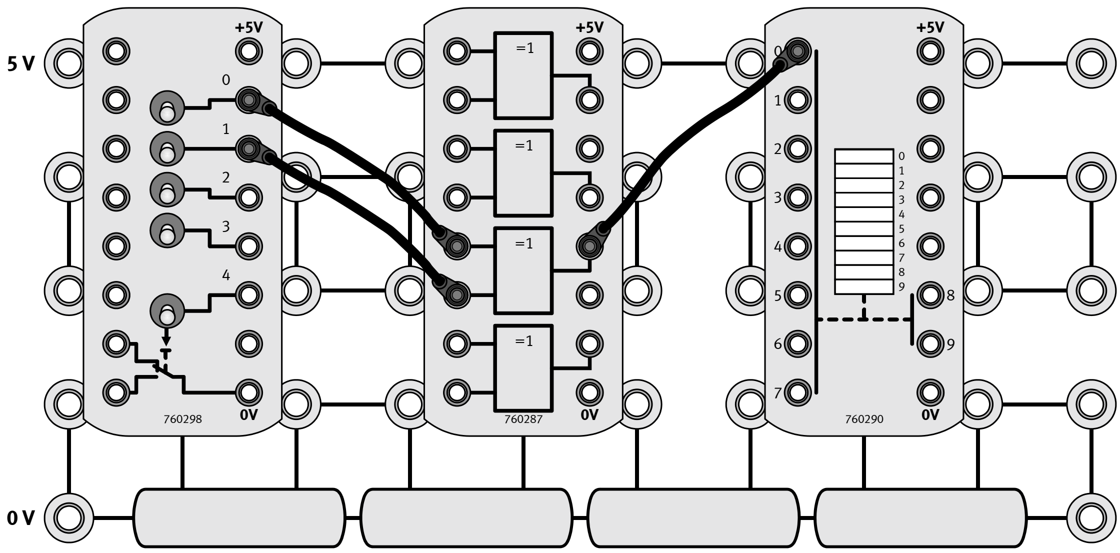
a) Sketch a circuit with two pushbuttons, one XOR gate and one LED. The LED should light up precisely when one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
XOR with 2 inputs	1 XOR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

9. Logic operations with more than two inputs

Information – modules with more than two inputs

In addition to operations with two inputs, modules with more than two inputs are often used in actual practice. Gates with three or four inputs are most common, whereas gates with eight inputs are infrequent.

- **Truth table**

  With each additional input, the number of rows in the truth table is doubled.
  In the case of an operation with three inputs we already have eight different states, and with four inputs 16 states. Let's look at the value table for the AND operation with three inputs. As in the previous case, the output is only high precisely when a high level is applied to all inputs.

A	B	C	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Truth table for AND operation with three inputs

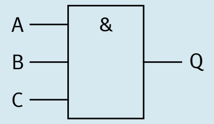
- **Operation equation**

  At the latest in the case of an AND gate with four inputs, it becomes apparent that the notation of logic operations with the help of a truth table is painstaking. This applies in particular when the relationship between the inputs and the output is relatively easy to describe, as is the case with the AND operation. Representation as an operation equation is usually quite compact, regardless of the number of inputs:

  AND operation with three inputs: $Q = A \wedge B \wedge C$

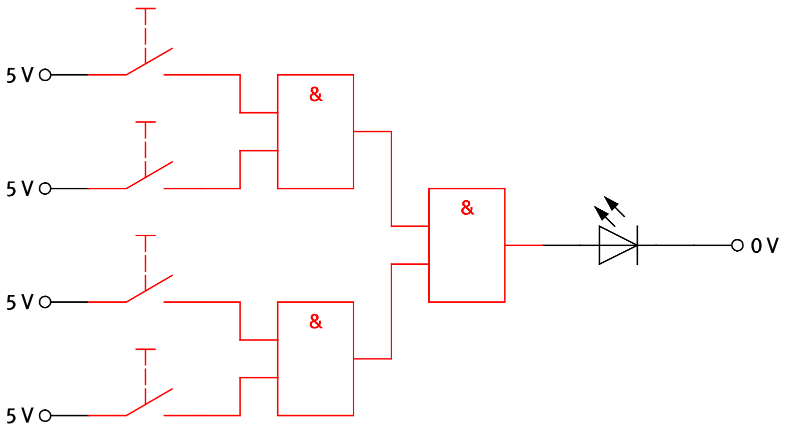
  NOR operation with four inputs: $Q = \overline{A \vee B \vee C \vee D}$

- **Circuit symbol**
  The circuit symbol is simply expanded to include any additional inputs. For example, the symbol for an AND operation with three inputs appears as follows:



Circuit symbol for the AND operation with three inputs

a) Sketch a circuit to implement a 4-fold AND operation only by using AND gates with 2 inputs. Set up the circuit and check it for correct functioning. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0, 1, 2 and 3
AND with 2 inputs	3 ANDs
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

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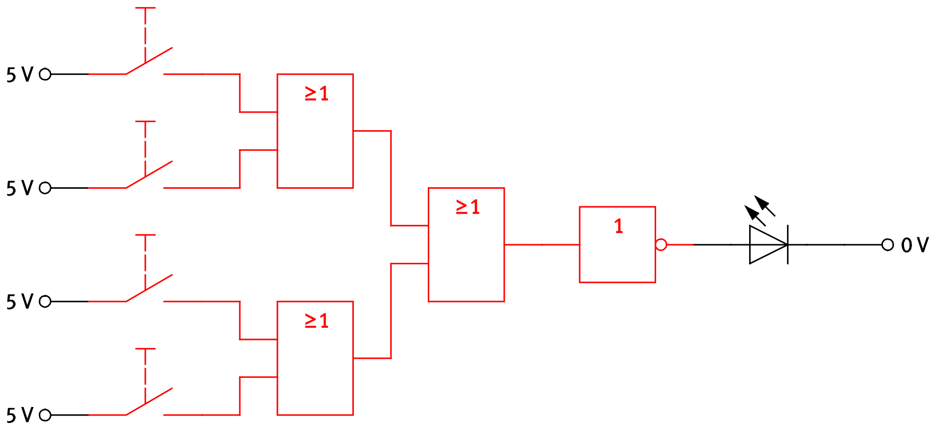
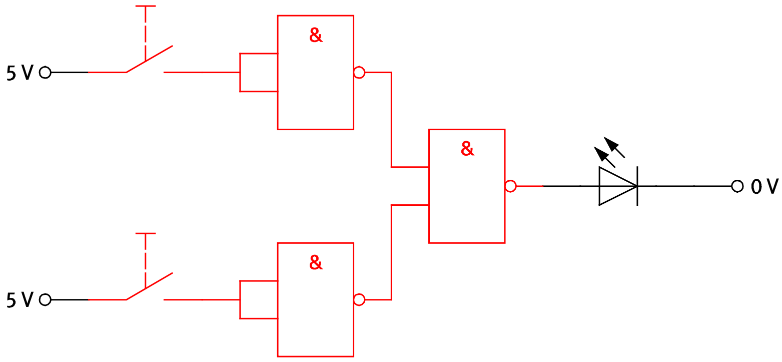
b) Sketch a circuit to implement a 4-fold OR operation only by using OR gates with 2 inputs and an inverter. Set up the circuit and check it for correct functioning.
Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0, 1, 2 and 3
OR with 2 inputs	3 ORs
Inverter / Schmitt trigger	1 inverter
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

c) Sketch a circuit to implement a 2-fold OR operation only by using NAND gates with 2 inputs. Set up the circuit and make sure it functions correctly. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
NAND with 2 inputs	3 NANDs
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

d) Prepare a truth table with three columns for inputs A, B and C, as well as three columns for outputs Q_1, Q_2 and Q_3. The following applies:
- $Q_1 = A \vee B \vee C$,
- $Q_2 = \overline{A \wedge B \wedge C}$ and
- $Q_3 = A \oplus B \oplus C$.

A	B	C	Q_1	Q_2	Q_3
0	0	0	0	1	0
0	0	1	1	1	1
0	1	0	1	1	1
0	1	1	1	1	0
1	0	0	1	1	1
1	0	1	1	1	0
1	1	0	1	1	0
1	1	1	1	0	0

e) Check the truth table by setting up circuits to implement the logic operations of the inputs.
Which circuits did you use? Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐

Q1: OR operation, 1 x OR with 4 inputs
Q2: NAND operation, 2 x NAND with 2 inputs, 1 x OR with 2 inputs
Q3: XOR operation, 3 x XOR with 2 inputs

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0, 1 and 2
OR with 4 inputs	1 OR, 4^{th} input: 0 V
NAND with 2 inputs	2 NANDs, 4^{th} input: 5 V
XOR with 2 inputs	3 XORs, 4^{th} input: 0 V
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

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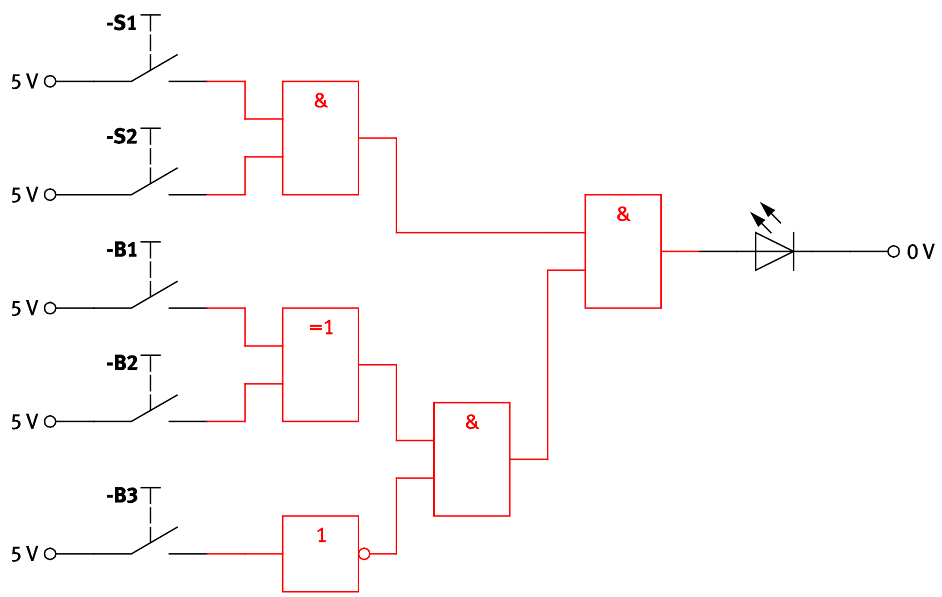
10. Combining different gates

Information – combining logic operations
In practice, different logic operations are usually needed in order to implement the required circuit logic.

a) Sketch a circuit which provides the required safety for the hydraulic press in the problem described at the beginning of the exercise. The press may only be activated
- when both start buttons (-S1 and -S2) are pressed, and
- material loaded into the press is detected by either sensor -B1 or sensor -B2.
- Additionally, integrated light barrier -B3 must not generate a signal.



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b) Set up the circuit and check it functions correctly. Simulate the input options with the help of switches and/or pushbuttons. Represent the status of the press with the help of an LED. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0, 1, 2, 3 and 4
AND with 2 inputs	3 ANDs
XOR with 2 inputs	1 XOR
Inverter / Schmitt trigger	1 inverter
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

Contents

Exercises and worksheets

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Exercise 1

Using elementary logic modules

Learning objectives

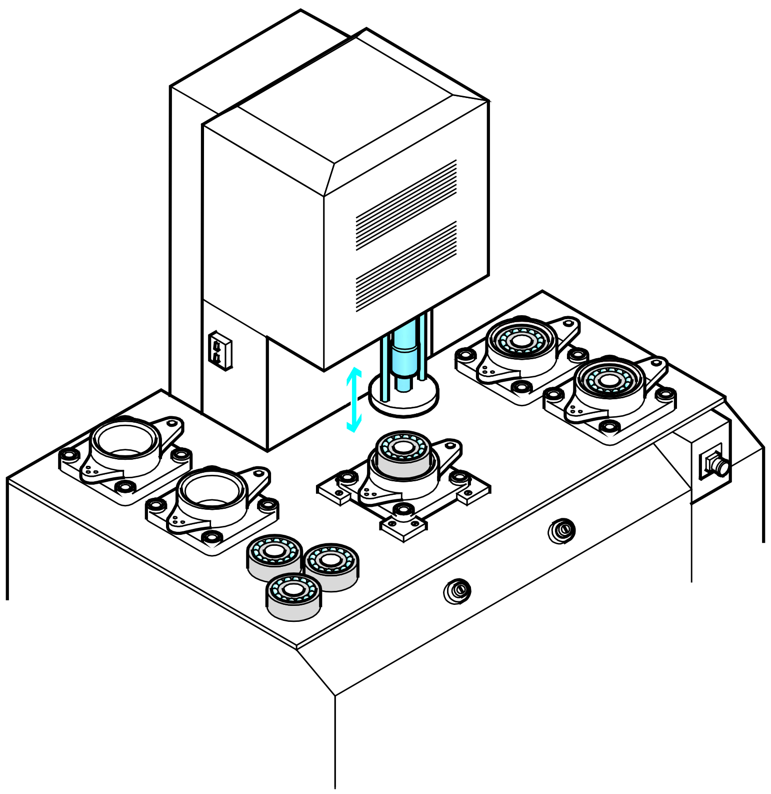
After completing this exercise:

- You'll be familiar with the most commonly used logic operators.
- You'll be familiar with the most important symbols.
- You'll be able to implement simple logic statements as circuits.

Problem description

A hydraulic press in a production facility is initially loaded with raw material, and then the pressing operation is triggered. Both tasks are executed by one person. In order to ensure the safety of the operator, he must only be able to activate the press when with each of his hands he presses a separate start button and the material is detected by either sensor 1 or sensor 2. As an additional safeguard, a check is carried out to determine whether or not the integrated light barrier is interrupted.

Layout



Hydraulic press

Work assignments

1. Research the term “binary states”.
2. Familiarise yourself with the different ways of representing logic operations.
3. Examine the NOT operation.
4. Examine the AND operation.
5. Examine the OR operation.
6. Examine the NAND operation.
7. Examine the NOR operation.
8. Examine the XOR operation.
9. Examine logic operations with more than two inputs.
10. Set up the circuit for controlling the hydraulic press.

Work aids

- Technical books
- Books of tables
- Operating instructions
- Data sheets
- Internet

1. Binary states

Information – binary states

Only two different voltage levels are used in the field of digital technology:

- High voltage
- Low voltage

Which voltage values are actually used for the two different levels depends on how the integrated circuits (ICs) used are implemented. In the case of typical transistor-transistor logic modules (TTL modules), high and low levels are 5 V and 0 V respectively (a voltage of 3.3 V is often used for high level at the moment).

In order to designate the voltage levels in abstract terms, the two logic states are usually called simply high and low, or the abbreviations 1 and 0 are used.

Common designations for binary states		
Logic designation	True	False
Voltage level, German	Hoch	Niedrig
Voltage level, English	High	Low
Binary format	1	0
Implementation	High voltage	Low voltage

– Type 74HCxx logic ICs are used in the set of components for “digital technology”.
Ascertain maximum low and high levels at the inputs and outputs for this series of ICs with a supply voltage of 4.5 V and 6 V. Enter the values in the table.

	Input		**Output**	
Supply voltage	**Low V_{IL}**	**High V_{IH}**	**Low V_{OL}**	**High V_{OH}**
4.5 V				
6 V				

2. Ways of representing logic operations

Information – logic operations

In digital circuits, several binary inputs are usually linked to a single output. For example, if a machine is only set into motion when pushbutton A as well as pushbutton B are pressed, we speak of an AND operation. If it's only necessary to press one of the pushbuttons, we're dealing with an OR operation.

The electronic modules by means of which logic operations are implemented are also called logic gates, or simply gates.

There are different ways in which logical relationships between several input signals and the associated output signal can be clearly represented; these are shown below.

- **Truth table**

  The relationship between the input and the output of a logic operation is represented in text form in a value table (or truth table). There's a row for each possible input assignment combination which describes the corresponding inputs signals and the associated output signal.

Input A	Input B	Output
Low	Low	Low
Low	High	Low
High	Low	Low
High	High	High

Truth table (comprehensive)

The following format is shorter, where variables A and B are used for the inputs and Q is used for the output. The logic levels are designated merely as 1 and 0.

A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

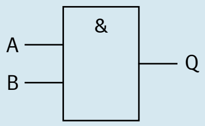
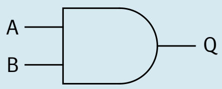
Truth table (condensed)

- **Operation equation**
  An operation equation can be used to represent a logic operation in an even more compact fashion than would be possible with a truth table. The relationship between the input and output signals is described by a mathematical equation in this case:

  Examples:
  – Q = A **AND** B
  – Q = A **OR** B
  – Q = **NOT** A **AND NOT** B

  In the following sections you'll learn the mathematical symbols for the **AND**, **OR** and **NOT** operations.

- **Circuit symbol**
  There are special symbols for the basic logic functions in order to be able to create digital circuits in the usual way in the form of circuit diagrams. The following table shows various symbols for the AND operation depending on which standard is used:

International standard EN 60617-12	**American standard ANSI 91-1984**
	

Circuit symbols for AND operations

Note
Only symbols in accordance with EN 60617-12 will be used on the following pages.

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3. NOT operation, inverter

Information – NOT operation

The simplest logic operation – with just one input signal and one output signal – is the NOT operation which is usually known as an inverter. The inverter turns the signal of the logic level around and thus generates a low level at the output from a high level at the input, or vice versa.

- **Truth table**

  The truth table for the NOT operation is very simple, because input variable A has only two possible assignments.

C	Q
0	1
1	0

Truth table for the NOT operation

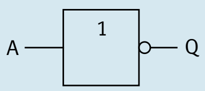
- **Operation equation**

  The inverted signal is identified by means of a horizontal line above the corresponding input variable:

  NOT operation $Q = \overline{A}$

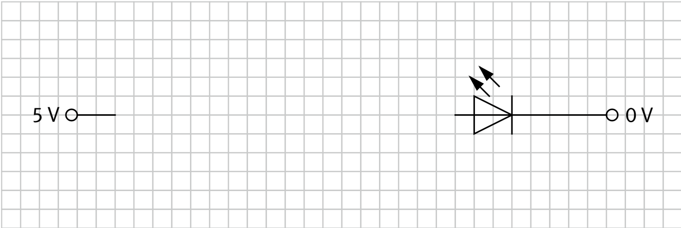
- **Circuit symbol**

  The following symbol is used for the inverter in a digital circuit (circuit diagram):

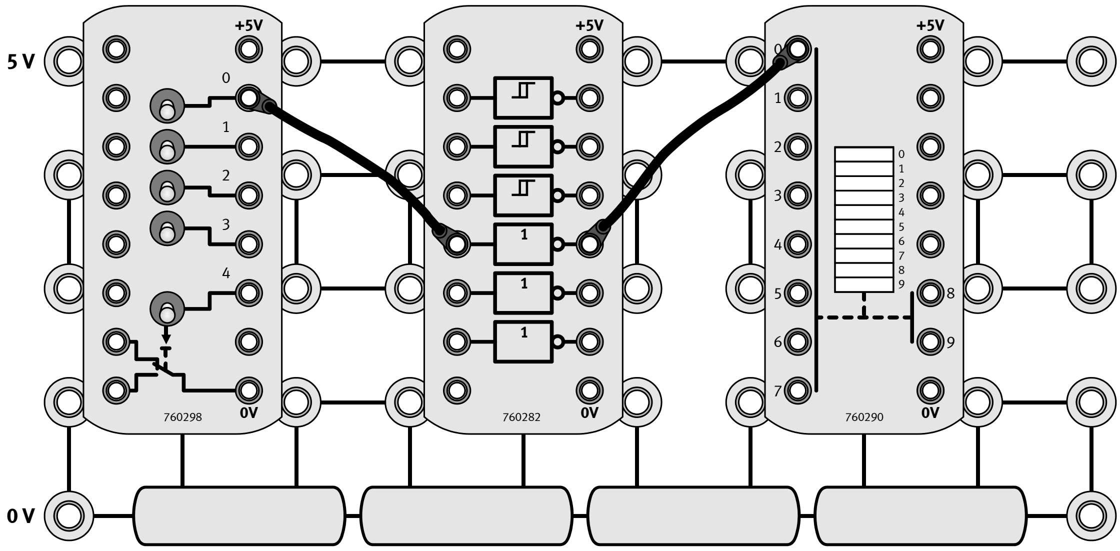


Circuit symbol for the NOT operation

a) Sketch a circuit with a pushbutton, an inverter and an LED. The LED should light up precisely when the pushbutton is not pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbutton 0
Inverter / Schmitt trigger	1 inverter
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

4. AND operation

Information – AND operation

As opposed to the inverter, the AND operation has two inputs which control the level of the output. The output level is only high when a high level is applied to both inputs.

- **Truth table**
  The truth table for the AND operation has four rows, because both input variables, A and B, have two possible assignments. Precisely when high potential is applied to both inputs, high potential is also read out at the output.

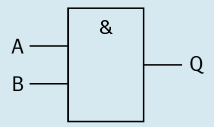
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

Truth table for the AND operation

- **Operation equation**
  The AND operation for two variables, A and B, is represented by a triangle open at the bottom between the variables:

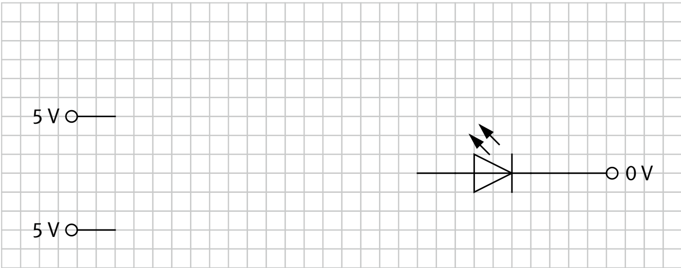
  AND operation: $Q = A \wedge B$

- **Circuit symbol**
  The circuit symbol indicates the logic operation by means of an ampersand (&):

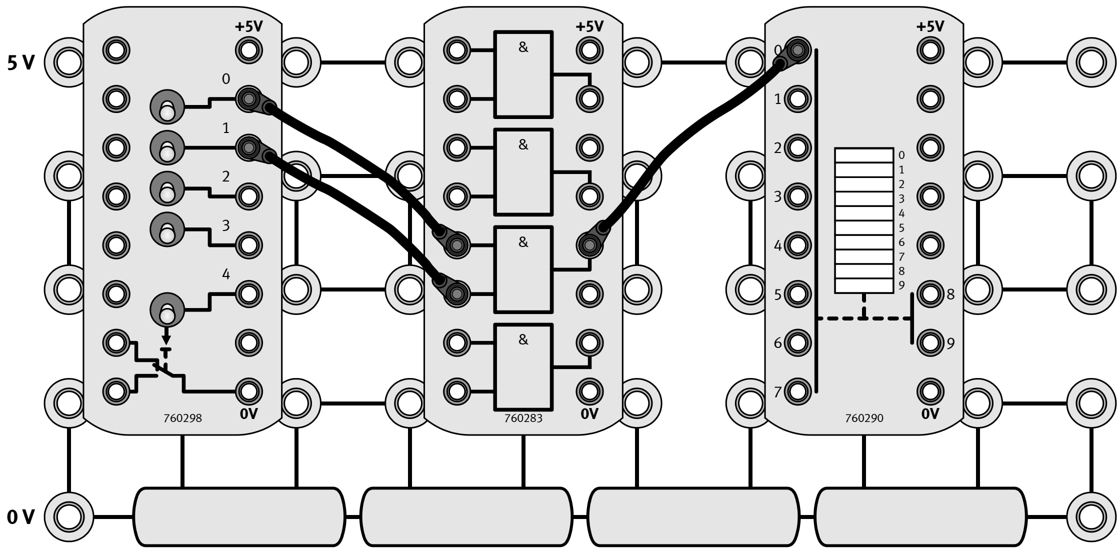


Circuit symbol for the AND operation

a) Sketch a circuit with two pushbuttons, one AND gate and one LED. The LED should light up precisely when both pushbuttons are pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
AND with 2 inputs	1 AND
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

5. OR operation

Information – OR operation

The OR operation is analogous to the AND operation, but in this case the output level is high whenever a high level is applied to at least one input.

- **Truth table**

  Like the AND operation, the OR operation has four possible input assignments. High potential is always read out at the output when at least one of the inputs is high.

A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

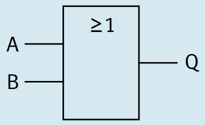
Truth table for the OR operation

- **Operation equation**

  The OR operation for two variables, A and B, is represented by a triangle open at the top between the variables:

  OR operation: $Q = A \vee B$

- **Circuit symbol**



Circuit symbol for the OR operation

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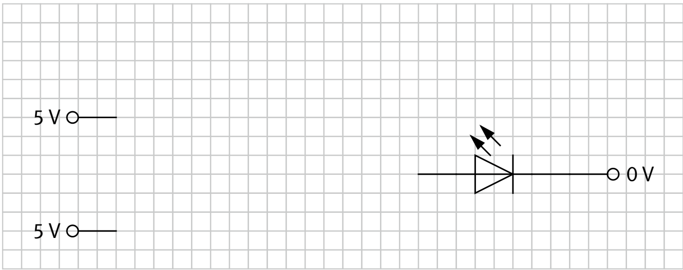
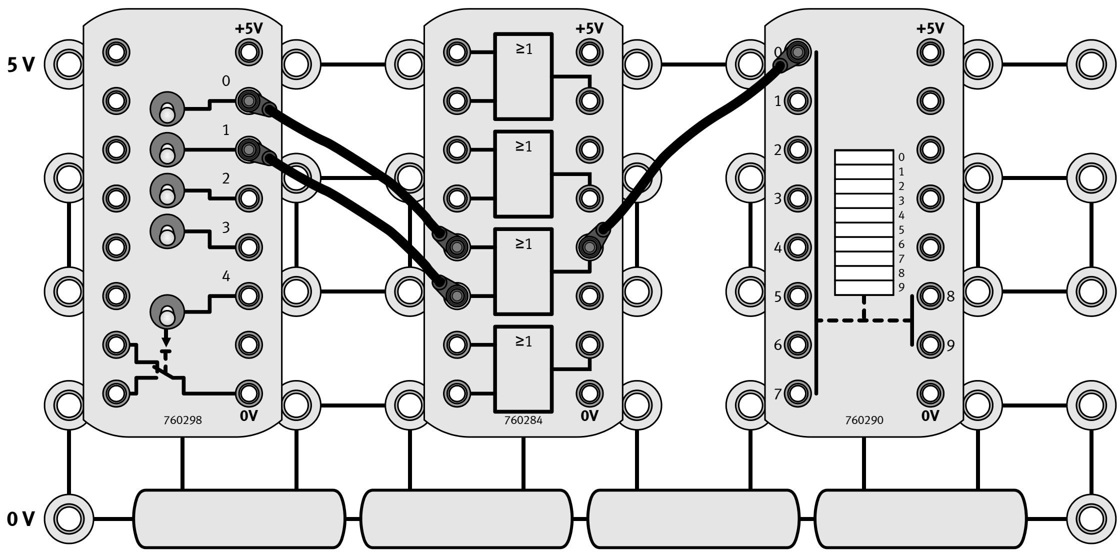
a) Sketch a circuit with two pushbuttons, one OR gate and one LED. The LED should light up as soon as at least one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
OR with 2 inputs	1 OR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

6. NAND operation

Information – NAND operation

In addition to the basic functions described thus far, the negated forms of the AND and OR operations are also used frequently. Within this context, negated (or inverted) means that the actual output level is reversed by means of a NOT gate.

- **Truth table**
  A comparison with the truth table for the AND operation reveals that the NAND operation delivers precisely the opposite output signal.

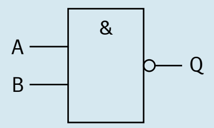
A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

Truth table for the NAND operation

- **Operation equation**
  The same symbol is used in the operation equation as is also the case for the AND operation. However, the negation line which appears above the entire equation indicates the final inverting step.

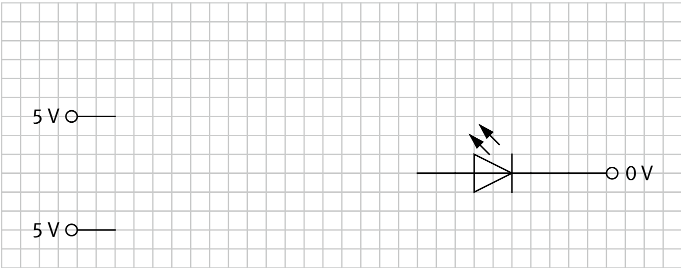
  NAND operation: $Q = \overline{A \wedge B}$

- **Circuit symbol**

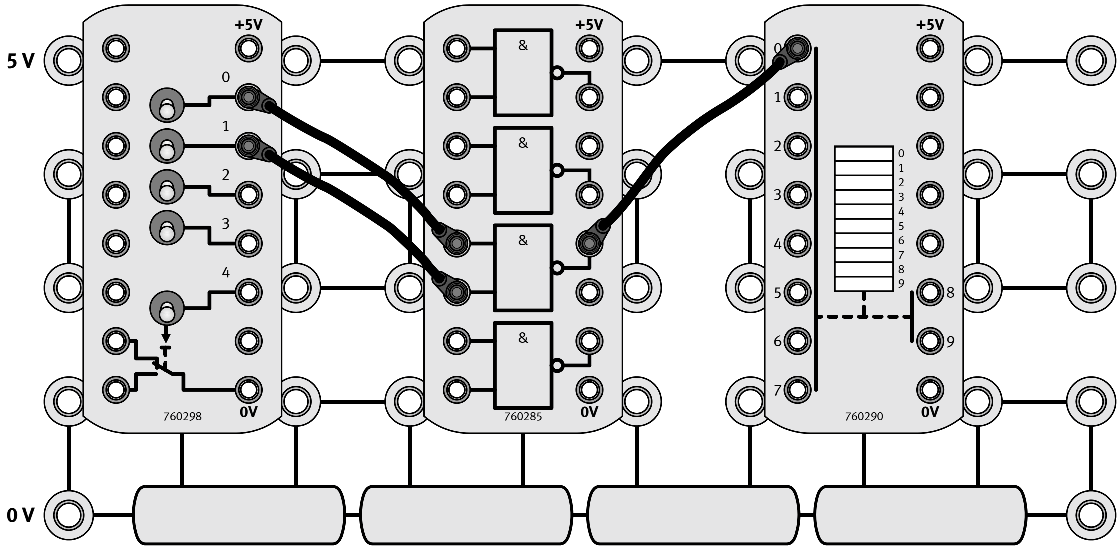


Circuit symbol for the NAND operation

a) Sketch a circuit with two pushbuttons, one NAND gate and one LED. The LED should go out precisely when both pushbuttons are pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit for to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
NAND with 2 inputs	1 NAND
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

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7. NOR operation

Information – NOR operation

Analogous to the NAND operation, the NOR operation results from an OR operation with a subsequent NOT gate.

- **Truth table**

  The NOR operation results in a high level output precisely when both input signals are at low level.

A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

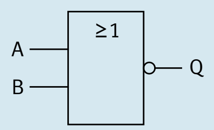
Truth table for the NOR operation

- **Operation equation**

  The operation equation shows the OR operation for A and B followed by the negation of the entire equation.

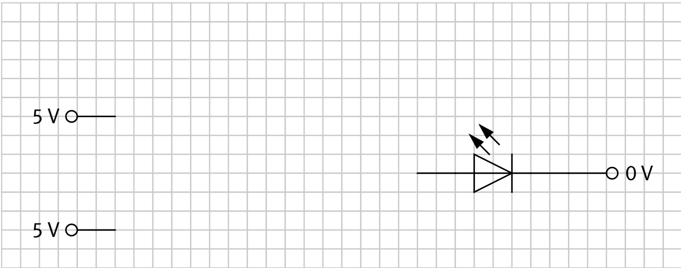
  NOR operation: $Q = \overline{A \vee B}$

- **Circuit symbol**

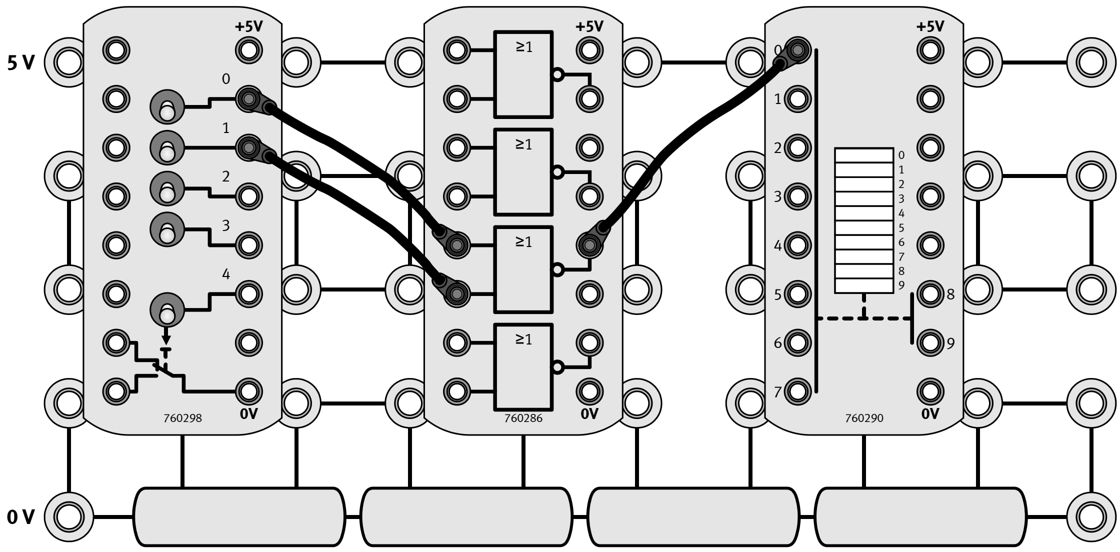


Circuit symbol for the NOR operation

a) Sketch a circuit with two pushbuttons, one NOR gate and one LED. The LED should go out as soon as at least one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
NOR with 2 inputs	1 NOR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

8. XOR operation (eXclusive OR)

Information – XOR operation

In the case of the so-called XOR operation, the output is high precisely when a high level is applied to one or the other input. If the same level is applied to both inputs, the output is low. And thus the XOR operation corresponds to the OR operation, except that a high output level only occurs when exclusively one input is high, thus resulting in the name “exclusive or”.

- **Truth table**
  The XOR operation results in a high level output precisely when one of the two input signals is at a high level.

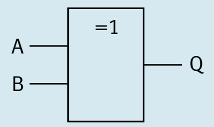
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

Truth table for the XOR operation

- **Operation equation**
  The XOR operation for A and B is made apparent in the operation equation by the operator, which consists of a circle with a cross.

  XOR operation: $Q = A \oplus B$

- **Circuit symbol**



Circuit symbol for the XOR operation

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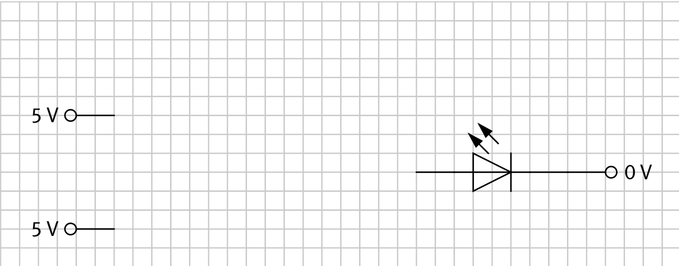
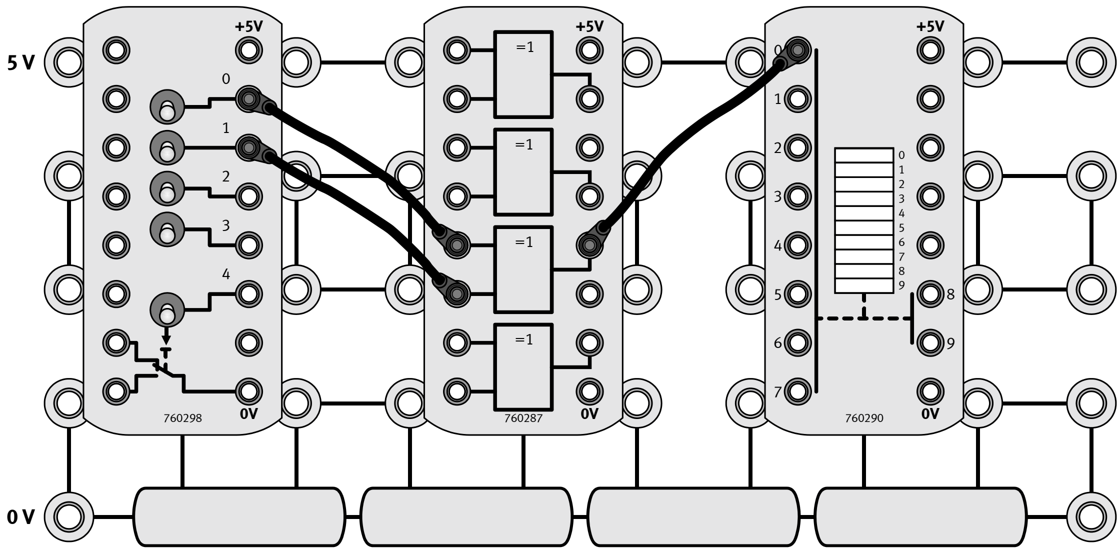
a) Sketch a circuit with two pushbuttons, one XOR gate and one LED. The LED should light up precisely when one of the two pushbuttons is pressed.



b) Set up the circuit with the modules.
Draw in the necessary connecting cables.
Check the circuit to make sure it functions correctly.
Tick the box on the right after the task has been successfully completed. ☐



Connection diagram

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	Pushbuttons 0 and 1
XOR with 2 inputs	1 XOR
LED bar graph with 10 digits	Input 0
Safety laboratory cables with 2 mm safety plugs	

Components list

9. Logic operations with more than two inputs

Information – modules with more than two inputs

In addition to operations with two inputs, modules with more than two inputs are often used in actual practice. Gates with three or four inputs are most common, whereas gates with eight inputs are infrequent.

- **Truth table**
  With each additional input, the number of rows in the truth table is doubled.
  In the case of an operation with three inputs we already have eight different states, and with four inputs 16 states. Let's look at the value table for the AND operation with three inputs. As in the previous case, the output is only high precisely when a high level is applied to all inputs.

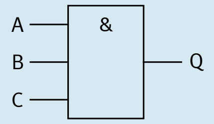
A	B	C	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Truth table for AND operation with three inputs

- **Operation equation**
  At the latest in the case of an AND gate with four inputs, it becomes apparent that the notation of logic operations with the help of a truth table is painstaking. This applies in particular when the relationship between the inputs and the output is relatively easy to describe, as is the case with the AND operation. Representation as an operation equation is usually quite compact, regardless of the number of inputs:

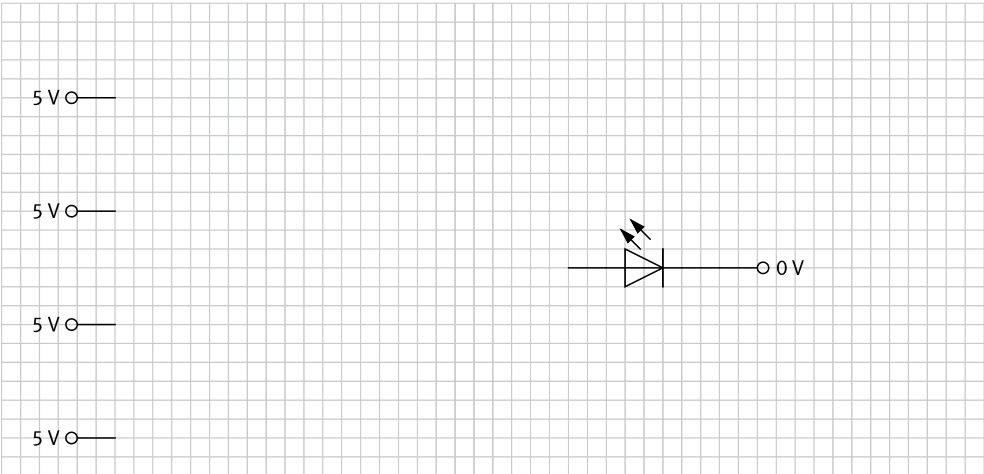
  AND operation with three inputs: $Q = A \wedge B \wedge C$
  NOR operation with four inputs: $Q = \overline{A \vee B \vee C \vee D}$

- **Circuit symbol**
  The circuit symbol is simply expanded to include any additional inputs. For example, the symbol for an AND operation with three inputs appears as follows:



Circuit symbol for the AND operation with three inputs

a) Sketch a circuit to implement a 4-fold AND operation only by using AND gates with 2 inputs. Set up the circuit and check it for correct functioning. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	
LED bar graph with 10 digits	
Safety laboratory cables with 2 mm safety plugs	

Components list

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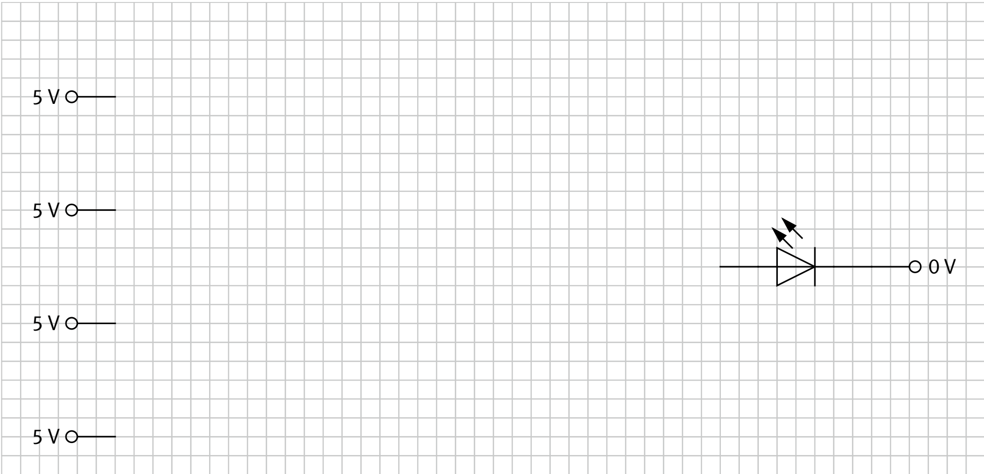
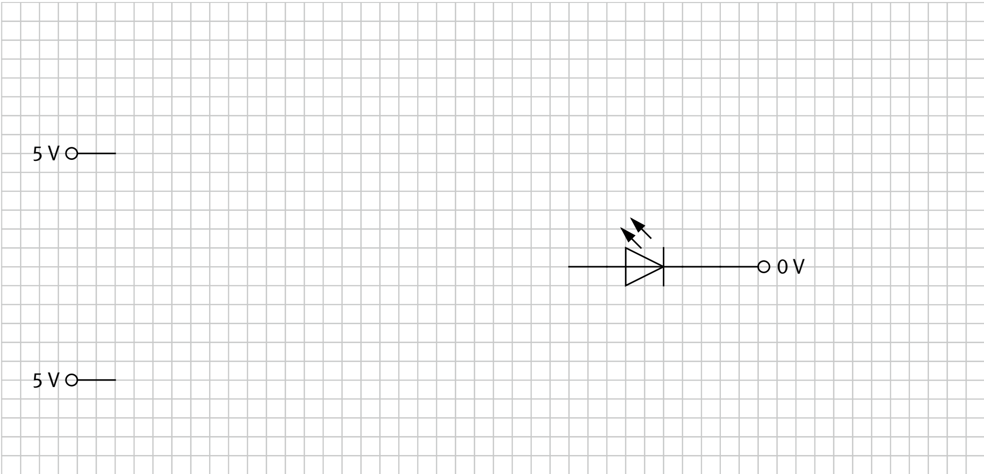
b) Sketch a circuit to implement a 4-fold OR operation only by using OR gates with 2 inputs and an inverter. Set up the circuit and check it for correct functioning. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	
LED bar graph with 10 digits	
Safety laboratory cables with 2 mm safety plugs	

Components list

c) Sketch a circuit to implement a 2-fold OR operation only by using NAND gates with 2 inputs. Set up the circuit and make sure it functions correctly. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐



Designation	Parameter
4-off control switch / pushbutton, single pushbutton	
LED bar graph with 10 digits	
Safety laboratory cables with 2 mm safety plugs	

Components list

d) Prepare a truth table with three columns for inputs A, B and C, as well as three columns for outputs Q_1, Q_2 and Q_3. The following applies:

– $Q_1 = A \vee B \vee C$,
– $Q_2 = \overline{A \wedge B \wedge C}$ and
– $Q_3 = A \oplus B \oplus C$.

A	B	C	Q_1	Q_2	Q_3
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

e) Check the truth table by setting up circuits to implement the logic operations of the inputs. Which circuits did you use? Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐

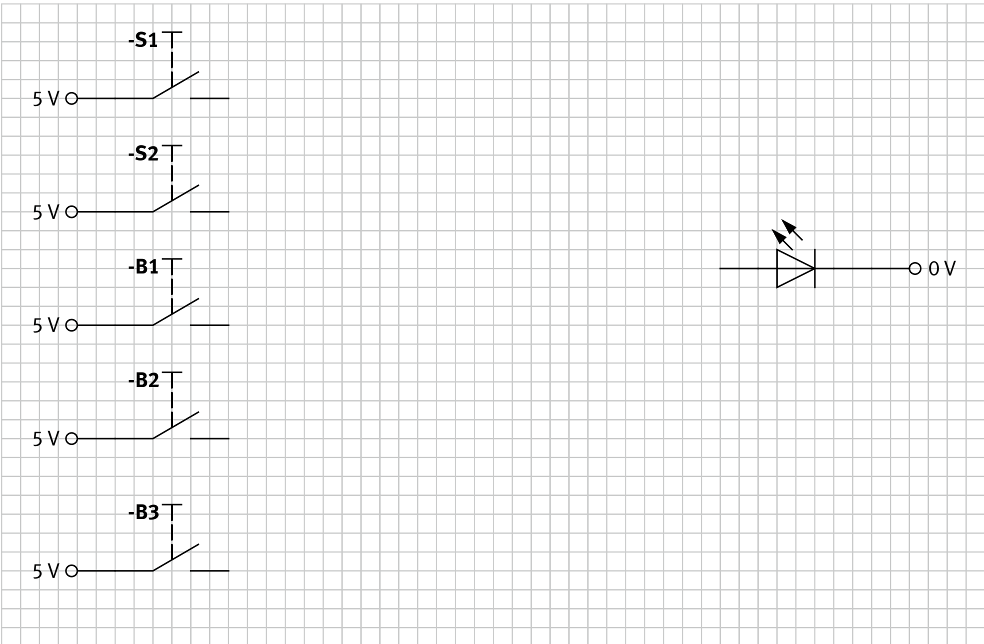
Designation	Parameter
4-off control switch / pushbutton, single pushbutton	
LED bar graph with 10 digits	
Safety laboratory cables with 2 mm safety plugs	

Components list

10. Combining different gates

Information – combining logic operations
In practice, different logic operations are usually needed in order to implement the required circuit logic.

a) Sketch a circuit which provides the required safety for the hydraulic press in the problem described at the beginning of the exercise. The press may only be activated
- when both start buttons (-S1 and -S2) are pressed, and
- material loaded into the press is detected by either sensor -B1 or sensor -B2.
- Additionally, integrated light barrier -B3 must not generate a signal.



b) Set up the circuit and check it functions correctly. Simulate the input options with the help of switches and/or pushbuttons. Represent the status of the press with the help of an LED. Complete the following table.
Tick the box on the right after the task has been successfully completed. ☐

Designation	Parameter
4-off control switch / pushbutton, single pushbutton	
LED bar graph with 10 digits	
Safety laboratory cables with 2 mm safety plugs	

Components list