

# PRINCIPLES OF PNEUMATICS

**Pressure:**

The ratio between a force and the surface on which it acts.

$$P = \frac{F \text{ (N)}}{S \text{ (m}^2\text{)}} = \text{Pa}$$

**Atmospheric pressure:**

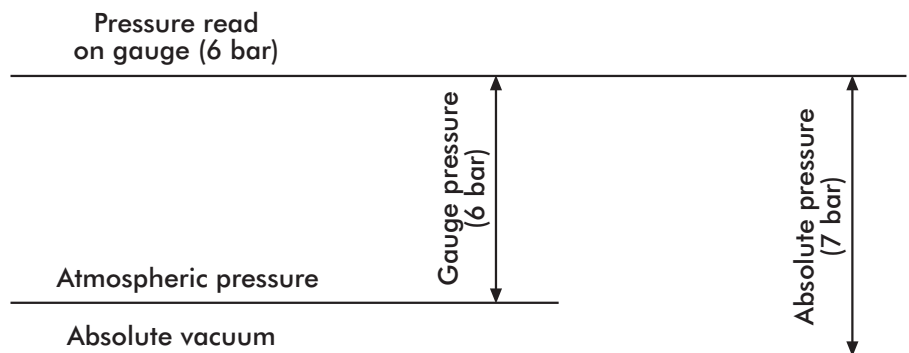
Equivalent to the pressure exerted on a surface at sea level at 20°C and with 65% humidity: 10.33 m H<sub>2</sub>O; 760 mm Hg; 1.013 x 10<sup>5</sup> Pa.

**Absolute pressure:**

The pressure above the absolute zero value - pressure 0 = absolute vacuum.

**Gauge pressure:**

The pressure referring to ambient atmospheric pressure: it is normally indicated by the pressure gauges used in pneumatic circuits.



$$\text{Gauge pressure} = (\text{absolute P}) - (\text{atmospheric P})$$

**Upstream pressure:**

Pressure of the compressed air at the pneumatic component inlet

**Downstream pressure:**

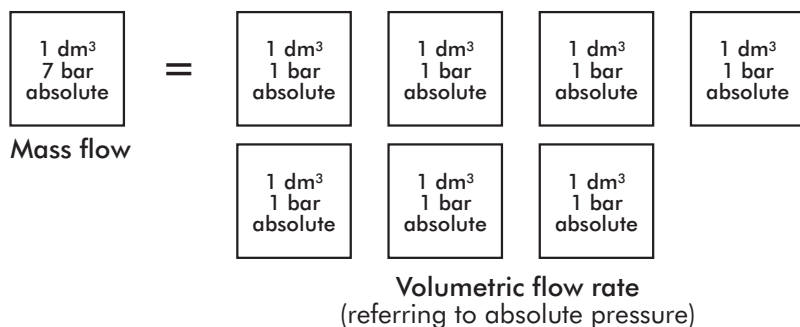
Pressure of the compressed air at the pneumatic component outlet

**ΔP pressure drop:**

Difference between upstream and downstream pressure

**FLOW RATE:**

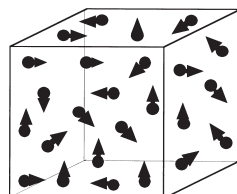
The volume of air passing through a given section in a unit of time. In pneumatics, the volume unit of measurement is NI (Normal litre). In practice it represents the volumetric capacity of the air referring to ambient atmospheric pressure. E.g. in a conduit of a given section, there is a mass flow of 1 litre of air (1 dm<sup>3</sup>) at 7 bar absolute pressure. This value expressed as volume of air corresponds to 7 litres of air (7 dm<sup>3</sup>) at the ambient atmospheric pressure (1 bar).



- With the same pressure, the flow rate is directly proportional to the port cross section.
- With the same cross section, the pressure is directly proportional to the flow rate.
- Without a ΔP (difference between upstream and downstream pressure), there can be no flow rate.

**Pascal's law:**

A confined fluid transmits externally applied pressure uniformly in all directions.



- Density of air, measured to 20°C to the atmospheric pressure:

$$1.275 \frac{\text{kg}}{\text{m}^3}$$

### CALCULATING THE FLOW RATE OF A VALVE USING FLOW COEFFICIENT $K_v$

Coefficient  $k_v$  gives approximate values when used for compressed air.  
The flow rate  $Q_N$  at a normal volume through a valve is:

$$\text{Subsonic flow: } P_2 > \frac{P_1}{2}$$

$$\text{Supersonic flow: } P_2 < \frac{P_1}{2}$$

$$Q_N = 28,6 \cdot k_v \cdot \sqrt{P_2 \cdot \Delta P} \cdot \sqrt{\frac{293}{273 + t}}$$

$$Q_N^* = 14,3 \cdot k_v \cdot P_1 \cdot \sqrt{\frac{293}{273 + t}}$$

where

$Q_N$  = flow rate at a normal volume [NI/min]

$Q_N^*$  = critical flow rate at a normal volume [NI/min]

$k_v$  = hydraulic coefficient in  $\frac{l}{min} \left( \frac{kg}{dm^3 \cdot bar} \right)^{1/2}$

$P_1$  = absolute upstream pressure [bar]

$P_2$  = absolute downstream pressure [bar]

$\Delta P$  = difference in pressure  $P_1 - P_2$  [bar]

$t$  = input air temperature [°C]

### CALCULATING THE FLOW RATE OF A VALVE USING FLOW COEFFICIENTS $C$ and $b$

The flow rate  $Q_N$  at a normal volume through a valve is:

$$\text{Subsonic flow: } P_2 > b \cdot P_1$$

$$\text{Supersonic flow: } P_2 < b \cdot P_1$$

$$Q_N = C \cdot P_1 \cdot \sqrt{1 - \left( \frac{r-b}{1-b} \right)^2} \cdot \sqrt{\frac{293}{273 + t}}$$

$$Q_N^* = C \cdot P_1 \cdot \sqrt{\frac{293}{273 + t}}$$

where

$Q_N$  = flow rate at a normal volume [NI/min]

$Q_N^*$  = critical flow rate at a normal volume [NI/min]

$C$  = conductance in [NI/min · bar]

$P_1$  = absolute upstream pressure [bar]

$P_2$  = absolute downstream pressure [bar]

$r$  = upstream pressure : downstream pressure ratio  $P_2 / P_1$

$b$  = critical pressure ratio  $b = P_2^* / P_1$

$t$  = input air temperature [°C]

### CALCULATING THE FLOW RATE OF A VALVE USING FLOW COEFFICIENTS $C_v$

The flow rate  $Q_N$  at a normal volume through a valve is:

$$\text{Subsonic flow: } P_2 > 0,528 \cdot P_1$$

$$\text{Supersonic flow: } P_2 < 0,528 \cdot P_1$$

$$Q_N = 400 \cdot C_v \cdot \sqrt{P_2 \Delta P} \cdot \sqrt{\frac{273}{273 + t}}$$

$$Q_N^* = 200 \cdot C_v \cdot P_1 \cdot \sqrt{\frac{273}{273 + t}}$$

where

$Q_N$  = flow rate at a normal volume [NI/min]

$Q_N^*$  = critical flow rate at a normal volume [NI/min]

$C_v$  = coefficient of flow [US · GPM / p.s.i.]

$P_1$  = absolute upstream pressure [bar]

$P_2$  = absolute downstream pressure [bar]

$t$  = input air temperature [°C]

## CALCULATING THE NOMINAL FLOW RATE

The nominal flow rate  $Q_{Nn}$  of a valve, i.e. the flow at normal volume passing through a valve with  $P_1 = 6$  [bar] ( $P_1 = 7$  [bar] absolute) and  $\Delta P = 1$  [bar], can be obtained from the previous formula as follows:

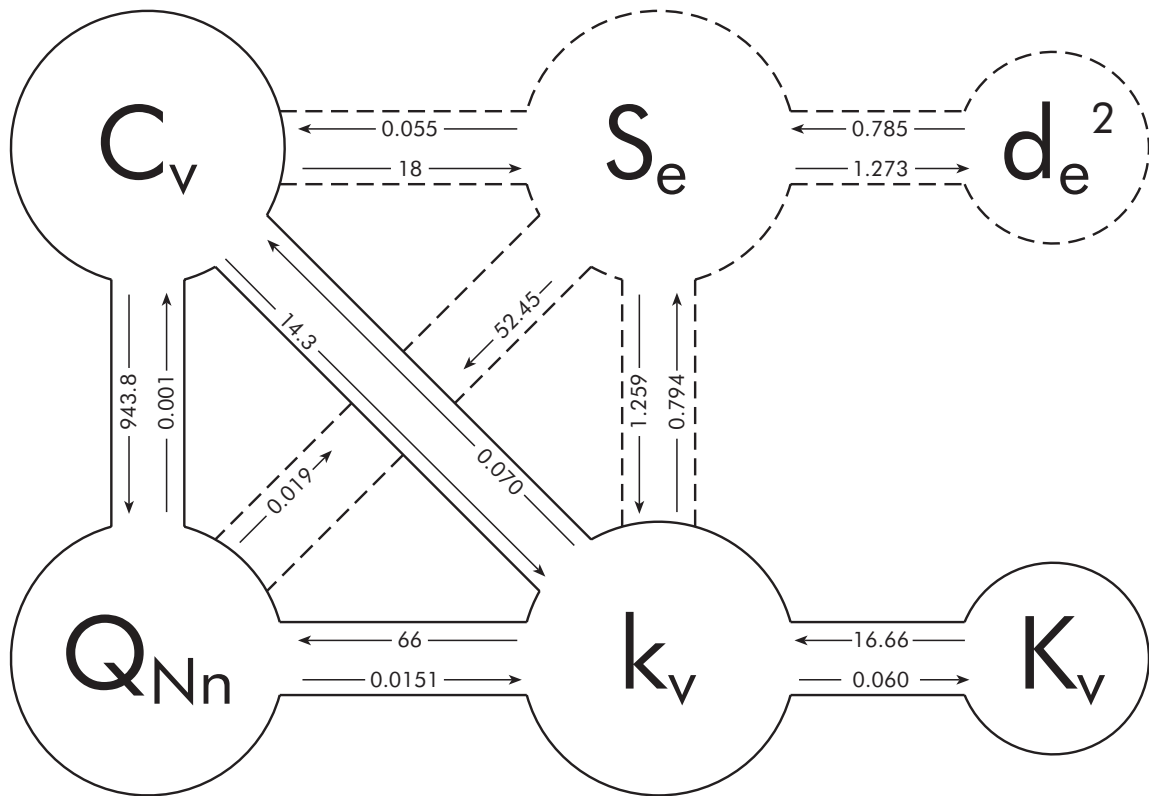
$$Q_{Nn} = 66 \cdot k_v$$

$$Q_{Nn} = 943,8 \cdot C_v$$

$$Q_{Nn} = 7 \cdot C \cdot \sqrt{1 - \left(\frac{0,857 - b}{1 - b}\right)^2}$$

Equalising the first two formulae gives:  $k_v = 14,3 \cdot C_v$

- REACTIONS BETWEEN  $Q_{Nn}$  -  $C_v$  -  $k_v$  -  $K_v$  -  $S_e$  -  $d_e^2$



$Q_{Nn}$  = flow rate in [Nl/min] with  $p_1 = 6$  [bar] ( $P_1 = 7$  [bar] absolute) and  $\Delta P = 1$  [bar]

$k_v$  hydraulic coefficient in  $\frac{l}{\min} \left( \frac{kg}{dm^3 \cdot bar} \right)^{1/2}$

$K_v$  hydraulic coefficient in  $\frac{m^3}{h} \left( \frac{kg}{dm^3 \cdot bar} \right)^{1/2}$

$C_v$  coefficient of flow [US · GPM / p.s.i.]

$S_e$  equivalent cross section [mm<sup>2</sup>]

$d_e^2 = S_e \cdot \frac{4}{\pi}$  through diameter<sup>2</sup> in [mm<sup>2</sup>] obtained from the equivalent cross section

# CONVERSION TABLES

**TABLE 1 – CONVERSION BETWEEN SYSTEMS OF MEASUREMENT**

	Technical system and CGS system	Multiply by	International system	Multiply by	British system
Length	m	1	m	0,0254	in (inch)
			m	0,3048	ft (foot)
Time	s	1	s	1	s
Area	m <sup>2</sup>	1	m <sup>2</sup>	0,000645	in <sup>2</sup>
			m <sup>2</sup>	0,0929	ft <sup>2</sup>
Volume	m <sup>3</sup>	1	m <sup>3</sup>	16,39·10 <sup>-4</sup>	in <sup>3</sup>
			m <sup>3</sup>	0,02832	ft <sup>3</sup>
Speed	m·s <sup>-1</sup>	1	m·s <sup>-1</sup>	0,3048	ft·s <sup>-1</sup>
Acceleration	m·s <sup>-2</sup>	1	m·s <sup>-2</sup>	0,3048	ft·s <sup>-2</sup>
Mass	kg·s <sup>-2</sup> ·m <sup>-1</sup>	9,81	kg	0,4536	lb (pound)
			kg	14,594	slug = lb f ·s <sup>2</sup> ·ft <sup>-1</sup>
Force	kg o kp	9,81	N	4,4483	lb f (pound)
	kg	0,981	da N = 10 N		
Torque	kg·m	9,81	N·m	1,356	lb f ·ft
Density	kg·s <sup>-2</sup> ·m <sup>-1</sup>	9,81	kg·m <sup>-3</sup>	16,02	lb·ft <sup>-3</sup>
Specific weight	kg·m <sup>-1</sup>	9,81	N·m <sup>-3</sup>	157,16	lb f ·ft <sup>-3</sup>
Work, energy	kg·m	9,81	J	1,356	lb f ·ft
			KWh=3,6·10 <sup>6</sup> J		
Heat	Cal	4186	J	1055,1	BTU
Power	kg·m·s <sup>-1</sup>	9,81	W	1,3558	lb f ·ft·s <sup>-1</sup>
	CV	735	W	745,7	HP
Pressure	kg·m <sup>-2</sup>	9,81	Pa	6,8948·10	p.s.i.=lb f ·in <sup>-2</sup>
	kg·cm <sup>-2</sup>	9,81·10	Pa		
	kg·cm <sup>-2</sup>	0,981	bar = 10 <sup>5</sup> Pa		
Mass flow	kg·s·m <sup>-1</sup>	9,81	kg·s <sup>-1</sup>	0,4536	lb·s <sup>-2</sup>
Volume flow	m <sup>3</sup> ·s <sup>-1</sup>	1	m <sup>3</sup> ·s <sup>-1</sup>	0,02832	ft <sup>3</sup> ·s <sup>-1</sup>
Dynamic viscosity	Nl/min <sup>-1</sup>	0,0000167	Nm <sup>3</sup> · S <sup>-1</sup>	0,000472	SCFM
	kg·s·m <sup>-2</sup>	9,81	Pa·s	6,896	lb f ·s·in <sup>-2</sup>
Kinematic viscosity	Po (poise-system CGS)	0,1	Pa·s		
	m <sup>2</sup> ·s <sup>-2</sup>	1	m <sup>2</sup> ·s <sup>-2</sup>	0,0929	ft <sup>2</sup> ·s <sup>-1</sup>
	St (stokes-system CGS)	10 <sup>-4</sup>	m <sup>2</sup> ·s <sup>-2</sup>		
	Technical system and CGS system	Divide by	International system	Divide by	British system

**TABLE 2 – TEMPERATURE CONVERSION**

$$^{\circ}\text{F} = [1,8 \cdot ^{\circ}\text{C}] + 32$$

$$^{\circ}\text{C} = [^{\circ}\text{F} - 32] \cdot 0,55$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

$$^{\circ}\text{C} = \text{degrees Celsius}$$

$$^{\circ}\text{K} = \text{degrees Kelvin}$$

$$^{\circ}\text{F} = \text{degrees Fahrenheit}$$

**TABLE 3 – MULTIPLES AND SUB-MULTIPLES**

Name	Symbol	Value
tera	T	10 <sup>12</sup>
giga	G	10 <sup>9</sup>
mega	M	10 <sup>6</sup>
kilo	k	10 <sup>3</sup>
etto	h	10 <sup>2</sup>
deca	da	10
deci	d	10 <sup>-1</sup>
centi	c	10 <sup>-2</sup>
milli	m	10 <sup>-3</sup>
micro	μ	10 <sup>-6</sup>
nano	n	10 <sup>-9</sup>
pico	p	10 <sup>-12</sup>

**TABLE 4 – PRESSURE UNIT CONVERSION FACTORS**

To obtain the pressure for the following units, multiply the number given for the source units by the coefficient shown.

Source units	Pa	kPa	MPa	bar	mbar	kp/cm <sup>2</sup>	cm H <sub>2</sub> O	mm H <sub>2</sub> O	mm Hg	p.s.i.
Pa	1	10 <sup>-3</sup>	10 <sup>-5</sup>	10 <sup>-5</sup>	10 <sup>-2</sup>	10,1972·10 <sup>-6</sup>	10,1972·10 <sup>-3</sup>	101,972·10 <sup>-3</sup>	7,50062·10 <sup>-3</sup>	0,145038·10 <sup>-3</sup>
kPa	10 <sup>3</sup>	1	10 <sup>-3</sup>	10 <sup>-2</sup>	10	10,1972·10 <sup>-3</sup>	10,1972	7,50062	0,145038	
MPa	10 <sup>6</sup>	10 <sup>3</sup>	1	10	10 <sup>4</sup>	10,1972	10,1972·10 <sup>3</sup>	101,972·10 <sup>3</sup>	7,50062·10 <sup>3</sup>	0,145038·10 <sup>3</sup>
bar	10 <sup>5</sup>	10 <sup>2</sup>	10 <sup>-1</sup>	1	10 <sup>3</sup>	1,01972	1,01972·10 <sup>3</sup>	10,1972·10 <sup>3</sup>	750,062	14,5038
mbar	100	0,1	10 <sup>-4</sup>	10 <sup>-3</sup>	1	1,01972·10 <sup>-3</sup>	1,01972	10,1972	0,750062	14,5038·10 <sup>-3</sup>
kp/cm <sup>2</sup>	98,0665	98,0665	98,0665·10 <sup>-3</sup>	0,989665	980,665	1	1000	10.000	735,559	14,2233
cm H <sub>2</sub> O	98,0665	98,0665·10 <sup>-3</sup>	98,0665·10 <sup>-6</sup>	0,98665·10 <sup>-3</sup>	0,98665	10 <sup>-3</sup>	1	10	0,735559	14,2233·10 <sup>-3</sup>
mm H <sub>2</sub> O	9,80665	9,80665·10 <sup>-3</sup>	9,80665·10 <sup>-6</sup>	9,80665·10 <sup>-6</sup>	98,0665·10 <sup>-3</sup>	10 <sup>-4</sup>	0,1	1	73,5559·10 <sup>-3</sup>	14,2233·10 <sup>-3</sup>
mm Hg	133,322	133,322·10 <sup>-3</sup>	133,322·10 <sup>-3</sup>	1,33322·10 <sup>-3</sup>	1,33322	1,35951·10 <sup>-3</sup>	1,35951	13,5951	1	19,3368·10 <sup>-3</sup>
p.s.i.	6,894,76	6,89476	6,89476·10 <sup>-3</sup>	68,9476·10 <sup>-3</sup>	68,9476	70,307·10 <sup>-3</sup>	70,307	703,07	51,7149	1



**TABLE 8 - RECOMMENDED FLOW RATE**

Maximum recommended flow rate in NI/min for pneumatic circuit piping. Flow rate values are calculated as follows:

- pipes Ø 2 to Ø 12 with a pressure drop equal to 0.3% of operating pressure per metre of pipe.
- pipes Ø 15 to Ø 40 with a pressure drop equal to 0.15% of the operating pressure per metre of pipe.

Inside diameter in mm - Nominal diameter in gas inches											
Pressure bar	Ø 2	Ø 4	1/8" Ø 6	1/4" Ø 8	3/8" Ø 10	Ø 12	1/2" Ø 15	3/4" Ø 20	1" Ø 25	1 1/4" Ø 32	1 1/2" Ø 40
2	3,5	19	53	110	190	300	370	750	1350	2500	4300
4	6,2	35	97	200	350	550	700	1400	2400	4500	7800
6	9	50	140	290	500	800	1000	2000	3500	6500	11500
8	11,8	66	185	380	660	1050	1300	2600	4500	8500	15000
10	14,5	82	230	470	820	1300	1600	3250	5700	10500	18500

**TABLE 9 - INDICATIVE AIR CONSUMPTION FOR DIFFERENT TYPES OF EQUIPMENT**

Type of equipment	Consumption at full load NI/min.	Type of equipment	Consumption at full load NI/min.
6 mm Ø drill	300	Bench tamper	350
12 mm Ø drill	500	8 kg tamper	700
20 mm Ø drill	1150	10 mm Ø riveting machine	450
45 mm Ø drill	1650	20 mm Ø riveting machine	1000
M6 screwdriver or bolt screwer	300	4 kg chisel	380
M10 screwdriver or bolt screwer	400	6 kg chisel	500
M16 impulse screwer	1150	Small paint-spray gun	160
M25 impulse screwer	1650	Industrial paint-spray gun	500
1" Ø wheel grinder	350	1 mm Ø cleaning bellows	65
6" Ø disk grinder	1500	2 mm Ø cleaning bellows	250
9" Ø disk grinder	2100	5 mm Ø nozzle sandblasting machine	1600
Polishing machine	1200	8 mm Ø nozzle sandblasting machine	4200
1000 kg hoist	2150	Plaster sprayer	500
Spot welder	300	Heavy-duty concrete vibrator	2500
		35 kg concrete breaker	1650
		18 kg breaker	1850
		30 kg breaker	2850

## DEGREE OF PROTECTION

Norma EN 60529 e CEI 529

# IP 6 5

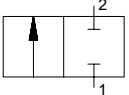

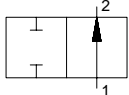

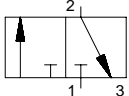

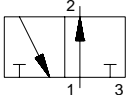

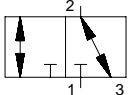

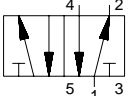

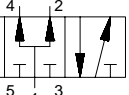

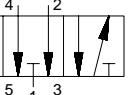

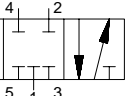

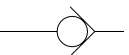



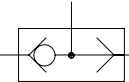

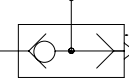



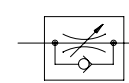

DEGREE OF PROTECTION AGAINST THE PENETRATION OF LIQUIDS

DEGREE OF PROTECTION AGAINST THE PENETRATION OF FOREIGN BODIES COMING INTO CONTACT WITH LIVE PARTS.

1 <sup>st</sup> No.	DESCRIPTION	2 <sup>nd</sup> No.	DESCRIPTION
0	Not protected	0	Not protected
1	Protected against solid bodies greater than Ø 50 mm	1	Protected against water falling vertically (condensate)
2	Protected against solid bodies greater than Ø 12 mm	2	Protected against drops of water falling up to 15° off the vertical
3	Protected against solid bodies greater than Ø 2.5 mm	3	Protected against rain water up to 60° off the vertical
4	Protected against solid bodies greater than Ø 1 mm	4	Protected against sprays of water from any direction.
5	Protected against dust	5	Protected against jets of water fired from any direction
6	Totally protected against dust	6	Protected against sea waves or the like
		7	Protected against the effects of immersion


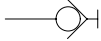

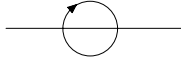

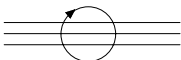





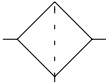

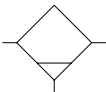

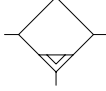

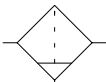
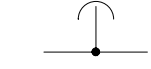
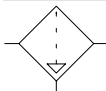

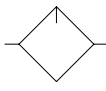




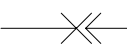
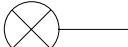
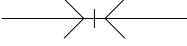
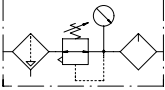
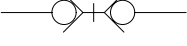
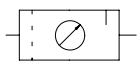

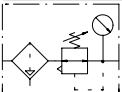
# PNEUMATIC SYMBOLS

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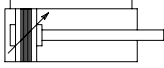
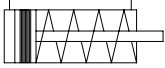
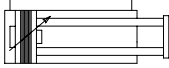
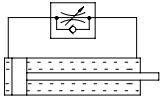
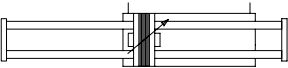
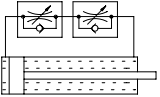
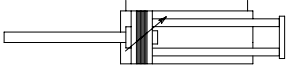
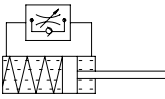

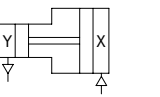
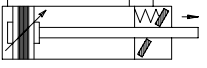
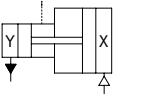
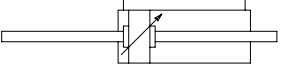
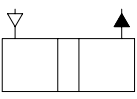
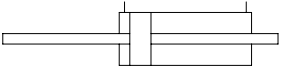

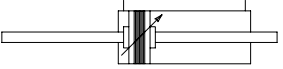

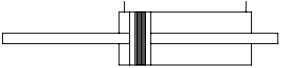

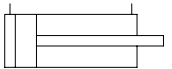

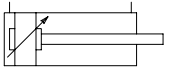

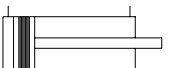


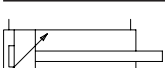
	2-way/ 2 positions valve(2/2) normally closed		Sequence valve
	2-way/ 2 positions valve(2/2) normally open		Pressure reducer without blowoff valve
	3-way/ 2 positions valve(3/2) normally closed		Pressure reducer with blowoff relief valve
	3-way/ 2 positions valve(3/2) normally open		Pressure piloted reducer with blowoff relief valve
	3-way/ 2 positions valve(3/2) NC-NO		Shutoff valve
	5-way /2 positions valve(5/2)		Dual pressure valve (AND element)
	5-way/ 3 positions valve(5/3) pressurized centres		Progressive pneumatic starter (APR)
	5-way/ 3 positions valve(5/3) open centres		Progressive solenoid starter (APR)
	5-way /3 positions valve(5/3) closed centres		Progressive pneumatic starter (APR) (SK 100 only)
	Unidirectional valve		Progressive solenoid starter (APR) (SK 100 only)
	Check valve with spring		3-way shutoff valve (V3V) with lockable control
	Circuit selector valve (OR element)		3-way shutoff valve (V3V) with pneumatic control
	Quick-release valve		3-way shutoff valve (V3V) with solenoid control
	Flow regulator with variable choke		2/2 progressive pneumatic valve (VAP) (SK 100 only)
	Unidirectional flow regulator with variable throat		2/2 progressive solenoid valve (VAP) (SK 100 only)



## TRANSMISSION AND PREPARATION

	Pneumatic pressure source		Quick-fit (de-coupling with closed terminal section)
	Operating line		1-way swivel coupling
	Pilot line		3-way swivel coupling
	Discharge line		Silencer
	Flexible line connection		Tank
	Electric cable		Filter
	Line connection (welding, screwing)		Condensate separator with manual discharge
	Line connection (welding, screwing)		Condensate separator with automatic discharge
	Crossing of unconnected lines		Filter with condensate separator with manual discharge
	Discharge point		Filter with condensate separator with automatic discharge
	Discharge hole without connection		Lubricator
	Discharge hole with connection		Pressure gauge
	Power pick-up point with closing cap		Pressure switch
	Power pick-up point with port		Optical tester
	Quick-fit coupling without unidirectional valve		FRL+pressure gauge maintenance unit
	Quick-fit coupling with unidirectional valve		FRL+pressure gauge simplified maintenance unit
	Quick-fit coupling (de-coupling with open terminal section)		FR+pressure gauge maintenance unit

**TRANSFORMATION**

	DE magnetic cylinder with adjustable bilateral cushioning		SE magnetic cylinder
	DE magnetic twin-rod cylinder with adjustable bilateral cushioning		Hydraulic brake with adjustment in one direction only
	DE magnetic twin-rod cylinder with adjustable bilateral cushioning		Hydraulic brake with adjustment in both directions
	DE magnetic twin-rod cylinder with adjustable bilateral cushioning-single through rod		Cushion
	DE magnetic cylinder with adjustable bilateral cushioning + DZB mechanical lock		Pressure multiplier for fluids with identical characteristics
	DE magnetic cylinder with adjustable bilateral cushioning + DZBA mechanical lock		Pressure multiplier for fluids with different characteristics
	DE cylinder with adjustable bilateral cushioning, through-rod		Pneumatic/hydraulic transducer
	DE through-rod cylinder		Constant volume compressor
	DE magnetic cylinder with adjustable bilateral cushioning, through-rod		Constant volume pneumatic motor, unidirectional flow
	DE magnetic cylinder, through-rod		Constant volume pneumatic motor, bidirectional flow
	DE cylinder		Variable volume pneumatic motor, unidirectional flow
	DE cylinder with cushioning		Variable volume pneumatic motor, bi-directional flow
	DE magnetic cylinder		Rotary pneumatic motor
	SE cylinder		Cylinder with adjustable single cushioning