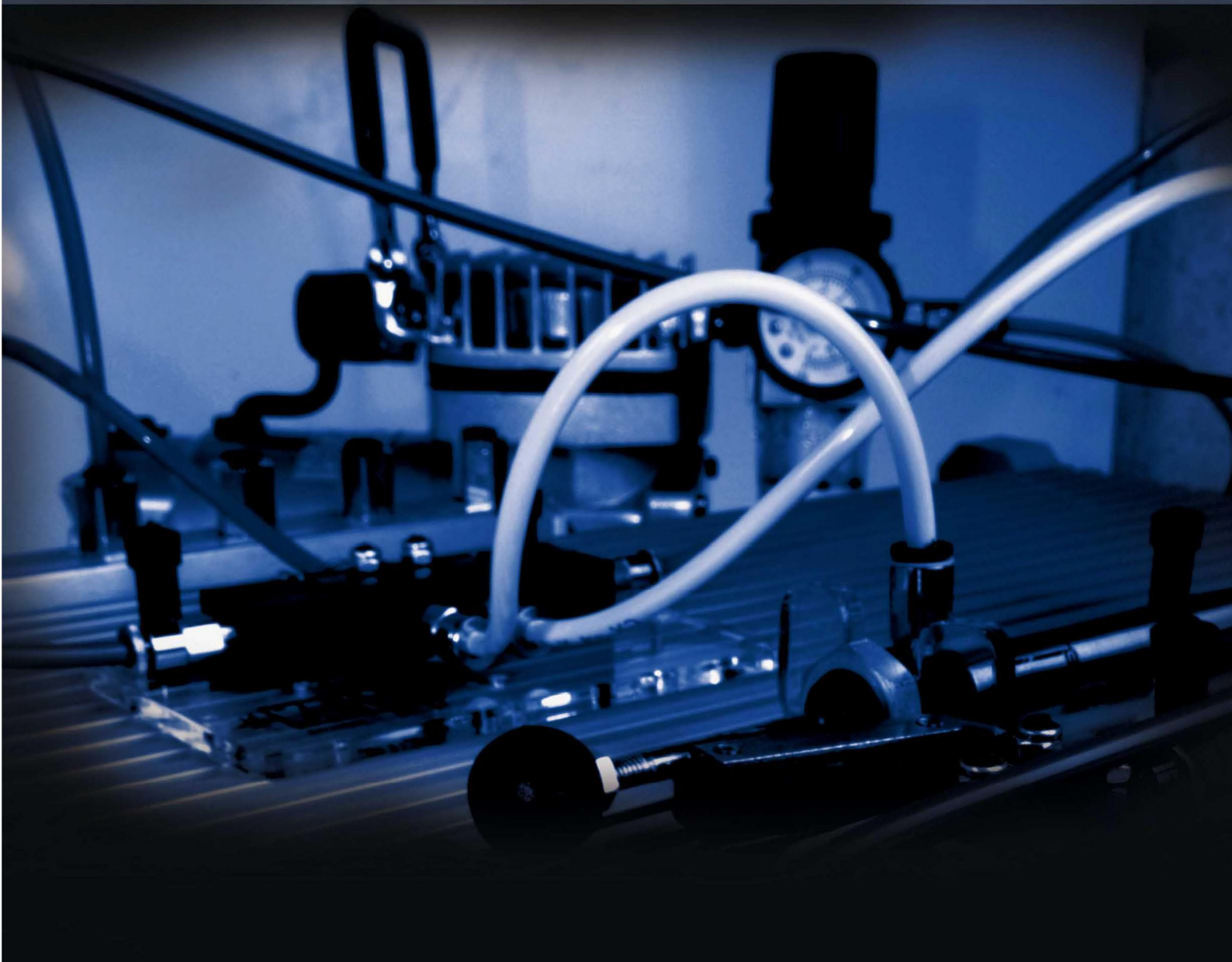


**MATRIX** | AUTOMATICS

**Automatics essentials**



AW2080

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### Safety Rules for Pneumatic Systems

Remember that compressed air and its components are capable of exerting large forces.

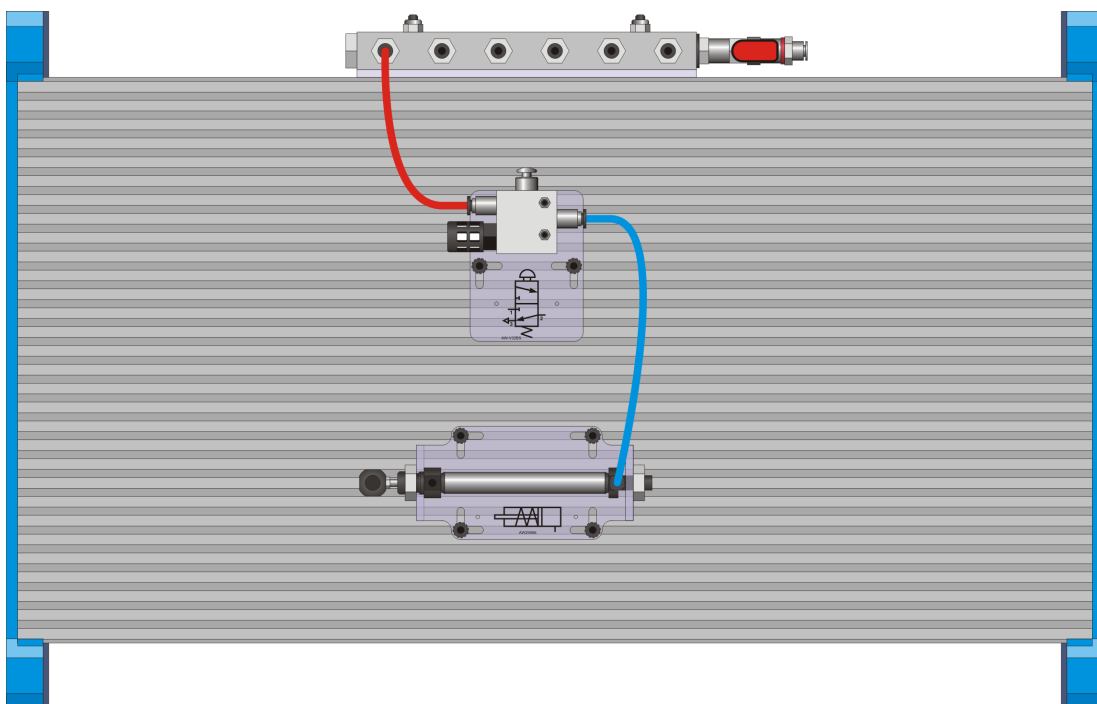


1. Never blow compressed air at anyone.
2. Don't turn on the air supply until the circuit is complete.
3. If you find an air leak, turn off the air supply at once.
4. Always turn off the air supply before you alter a circuit.
5. Keep fingers clear of moving parts such as piston rods.
6. Wear safety spectacles when building and operating pneumatic circuits.



### Over to you:

- **The red lever on the manifold must be turned off at this stage.**
- Build the arrangement shown below. It contains a single-acting cylinder, the one with only one port, connected to a push-button 3-port valve, then through one port of the manifold to the compressor.
- Turn on the air supply.
- Press the button on the valve and keep it pressed. What happens?
- Now release the button. What happens?
- Try it again. Can you work out how the system operates?



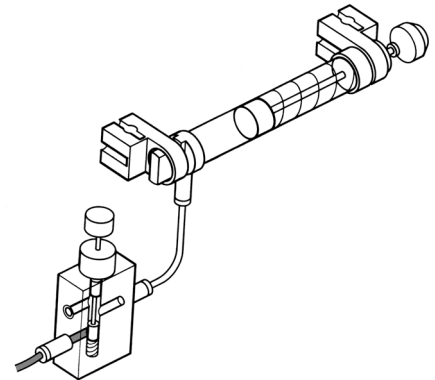
w1a

# Worksheet 1

## Safety first and last

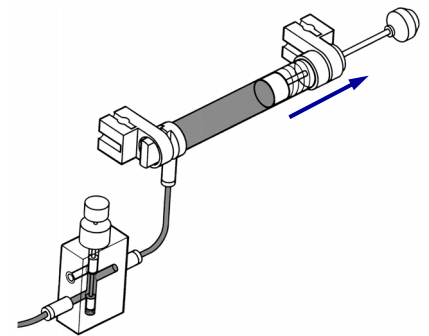
### So what?

- The top diagram shows the valve in its **unactuated** state. The button is not pressed, and the valve stops air flowing from the manifold into the cylinder. The cylinder is **retracted**.



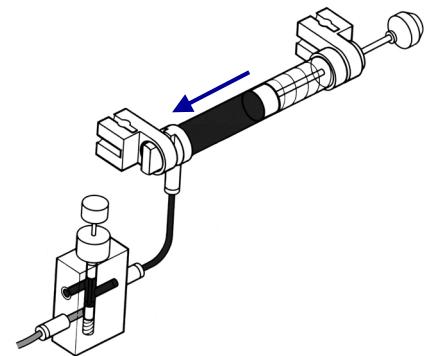
w1b

- When the button is pressed, the valve goes into its **actuated** state, and lets air flow into the cylinder. This pushes out the piston rod. The cylinder is now **extended**, as shown in the second diagram.



w1c

- When the button is released, the spring inside the valve pushes the disc back into the **unactuated** position. This allows air to flow from the cylinder, through the valve into the atmosphere. The cylinder spring can now push the piston back into the **retracted** position. You can hear and feel air coming out of valve port 3 as the cylinder retracts. This is called **exhausting** air and so port 3 is called the exhaust port.



w1d

### Pneumatics vs hydraulics:

- Fluid pressure in pneumatic control systems is ~ 10 times smaller than in hydraulic systems. As a result, pneumatic pistons must be ~ 10 times bigger in area to produce the same force.
- Hydraulic systems rely on the fact that liquids (the operating fluid) are incompressible.
- The working fluid in pneumatic systems (air) is very compressible. However, air is free, and is usually returned to the atmosphere. Hydraulic fluid is expensive, polluting and can be a health hazard. Leaks must be avoided at all costs.
- In pneumatic systems, air is compressed to the required pressure, but in the process it gets hot. In cooling it ready for use, some of the water vapour in it is deposited as condensation.
- In hydraulic systems, incompressibility means that speed can be controlled effectively by regulating the flow of the fluid to the cylinder, so that precise position control is achievable.

# Worksheet 1

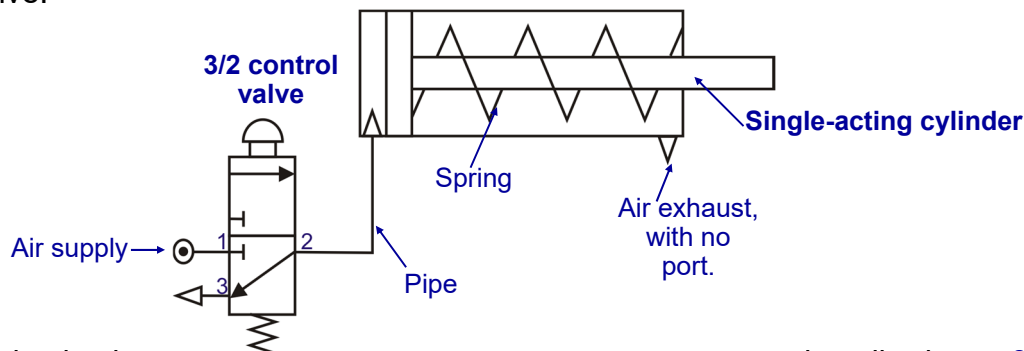
## Safety first and last

### So what?

Symbols:

You just used a 'picture' of the system to build the circuit. However, to describe the system to someone else, it is usually drawn as a conventional circuit diagram, using standard symbols for the components, rather like a circuit diagram in electricity.

Here is the pneumatic circuit diagram for the system you just built, using the push-button 3/2 control valve:



The control valve is described as a **3/2** valve because it has **3** ports and **2** states.

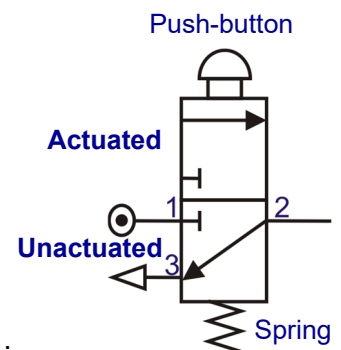
The ports are numbered **1** to **3** on the diagram, alongside one of the states.

The two states are **actuated**, when the push-button is pressed, and **unactuated**, when it is released and the spring takes over.

Each state is shown as a box. The valve has two states and so the symbol has two boxes.

One is attached to the push-button, and shows the effect of pushing it in. Here, air flows from the manifold (via port **1**) to the cylinder (via port **2**). The exhaust port (**3**) is blocked.

The other box, attached to the spring, shows what happens when the spring returns the valve to its unactuated state. Now, air from the manifold is blocked, (port **1**) and instead, the cylinder is connected (via port **2**) to the exhaust port (**3**).



### For your records:

- A control valve is described as a '*5/3 spool*' valve. Write a short (less than 25 words) description of this valve, covering all of the terms in italics.
- Using research on the internet or equivalent, create a table listing the relative advantages of pneumatic control systems and hydraulic control systems.
- Which type of control system would you use in:
  - a food factory;
  - earth-moving equipment?Give reasons for your choices.

# Worksheet 2

## Control the flow

There are three basic types of control system, electrical, hydraulic and pneumatic. There isn't a best or a worst. It all depends on the application.

**Electrical** control - for accuracy of movement or continuous motion, such as CNC machining, and in lift and locate assembly applications.

**Hydraulics** - for heavy loads, up to many tonnes, with immediate response or where full speed has to be achieved quickly.

**Pneumatics** - speed and force are controllable over a wide range.

Pneumatic control systems function reliably under adverse conditions such as high and low temperatures, dirt, vibration, moisture, and electrical noise, and are intrinsically safe and non-contaminating, in, for example, food processing areas or when there is a risk of fire or explosion.

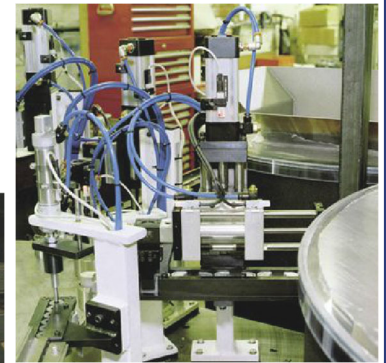
They are tolerant to overloads and stalling.



Pressing cheeses



Manipulating timber planks



Move and clamp operation in automatic assembly

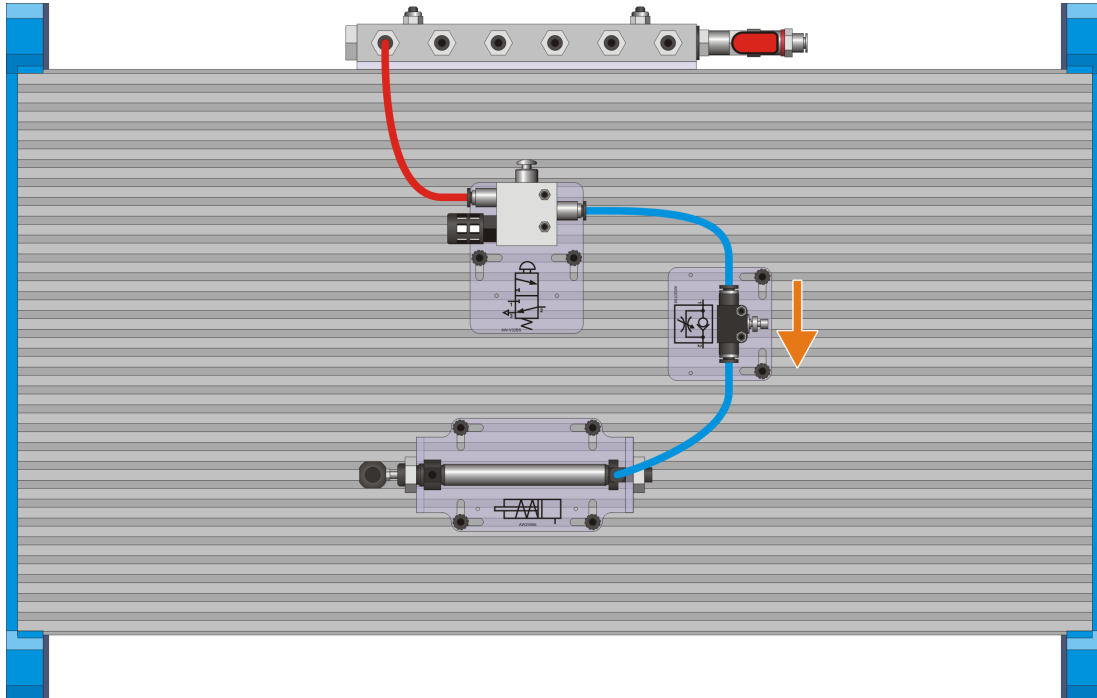
### Over to you:

- **Once again, the red lever on the manifold must be off at this stage.**
- Build the arrangement shown on the next page.  
It is the one built previously, with a flow control valve added. The arrow on the underside of the valve points towards the cylinder.
- Turn the screw on the flow control valve right down.
- Turn on the air supply.
- Push the button on the three port valve. The piston rod should move very slowly or not at all.
- Now withdraw the screw as far as it will go and push the button again.  
The piston rod moves much faster.
- Adjust the screw to give a moderate speed for the piston.
- **Turn the red lever to switch off the air supply.**
- Disconnect the flow control valve and re-connect it the other way round, (with the arrow pointing away from the cylinder.)
- Turn on the air supply, and press the button on the three port valve. Notice the difference.

# Worksheet 2

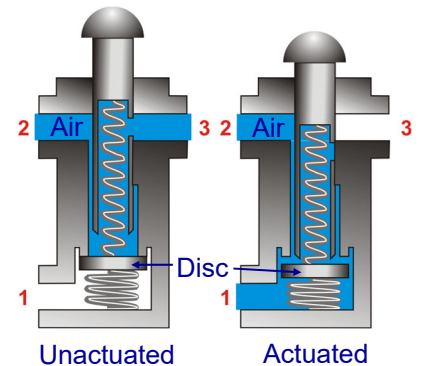
## Control the flow

### Layout for worksheet 2:



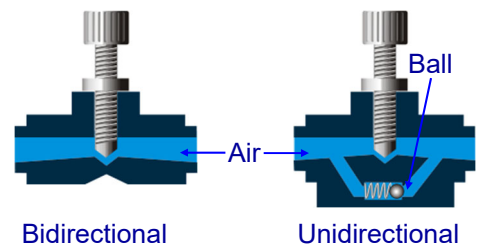
### So what?

- The diagram opposite shows the action of the 3/2 control valve.
- The exhaust port of a pneumatic valve is often fitted with a silencer, to reduce noise and prevent contaminating the port. The symbol for this is shown below:

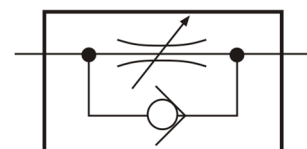


- Flow control valves can be either bidirectional, to reduce air flow in both directions, or unidirectional.

In unidirectional valves, an arrow on the base of the valve shows the direction of the **controlled** air route. In the one shown opposite, controlled flow is from left to right. Here, air pushes the ball against its seat, blocking the by-pass channel. Air must flow down the main restricted channel. When air flows the other way, it pushes the ball away from the seat, allowing full flow down the by-pass channel.



- The symbol for a flow-control valve is shown opposite:



controlled direction →

### So what?

Next, some definitions, and the units used to measure them:

- **Mass (m)** - measures how much matter (number of fundamental particles) in a body.  
- measured in kilograms (kg).
- **Force (F)** - a push or pull that causes motion, or stops it, or holds something in position.  
- measured in units called newtons (N).
- **Weight (W)** - the force which gravity exerts on a body.  
- also measured in newtons.
- **Pressure (P)**- the force exerted on unit area of a body.  
- measured in pascals (Pa), (1 Pa is a force of 1 N acting on an area of 1 m<sup>2</sup>.)
- These quantities are connected by the following equations:

$$W = m \times g$$

$$F = P \times A \text{ (or } P = F / A \text{ or } A = F / P)$$

where **g** is the gravitational field strength, usually taken as 10 N / kg.

The atmosphere we live in is about 8 km deep. Although we are not usually aware of it, this air has a considerable weight. As a result, it exerts an enormous pressure on everything it touches. Normal air pressure is taken to be roughly 100 kPa, or a force of 100 000 N pressing on every square metre of the surface of a body, though it varies with altitude and air temperature.

### Sample calculations:

1. What is the weight of a 2.5 kg object?

**Answer** - Using  $W = m \times g$ , the weight is  $2.5 \times 10 = 25$  N.

2. What pressure is exerted on the floor by a person weighing 850 N and having a combined foot area of 0.05 m<sup>2</sup>?

**Answer** - Using  $P = F / A$ , the pressure is  $850 / 0.05 = 17000$  Pa (also written as 17 kPa.)

3. What force is exerted on a piston of area 0.001 m<sup>2</sup> subjected to an air pressure of 500 kPa?

**Answer** - Using  $F = P \times A$ , the force is  $500\,000 \times 0.001 = 500$  N.

### For your records:

- Draw and label the symbols for the following pneumatic components:
  - single-acting cylinder
  - 3/2 push-button control valve
  - silencer
  - flow-control valve (showing the controlled direction.)
- Draw the pneumatic circuit diagram for the system you set up earlier in this worksheet.

# Worksheet 3

## Automatic door



A common use of pneumatics is in automatic doors, in buildings and vehicles.

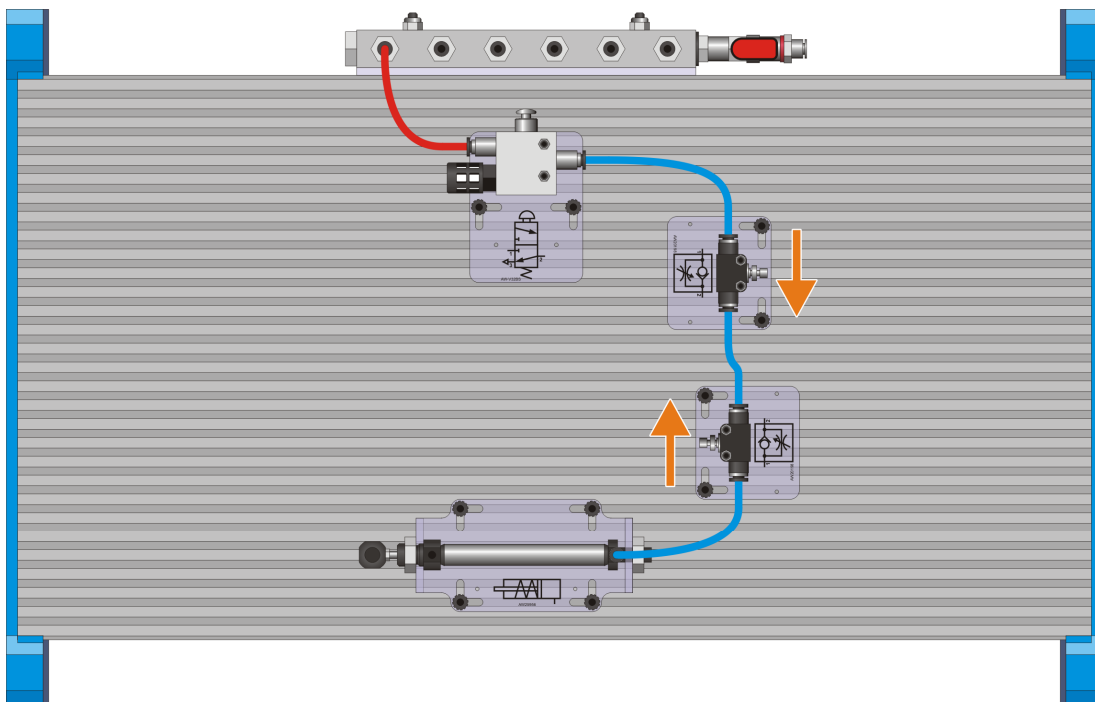
The control system must ensure that the door opens and closes at an appropriate speed - too fast, and it might injure someone or damage the hardware - too slow, and it delays people entering and leaving.

In the last worksheet, you used a unidirectional flow control valve to adjust the speed of a single-acting cylinder. Here, that system is extended to control speed in both extending and retracting, and a safety device and second switch are added.

w3a

### Over to you:

- **As before, the red lever on the manifold must be off whenever you modify the system.**
- Build the arrangement shown below - the one you just built, with another flow control valve added. The arrow on this second one points away from the cylinder.
- Adjust the screw on the second valve to match the first one.
- Turn on the air supply.
- Push the button on the 3-port valve. You should find that the piston now both extends and retracts at moderate speed. This could be connected to the door mechanism, and operate the door automatically when a button is pressed.



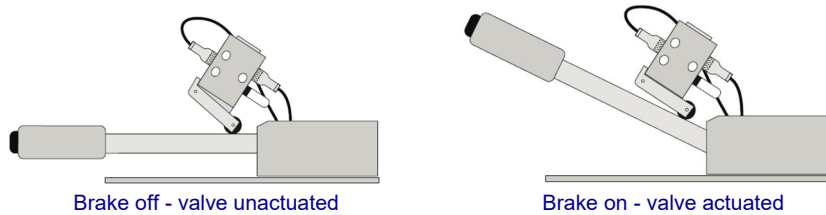
w3b

# Worksheet 3

## Automatic door

Over to you:

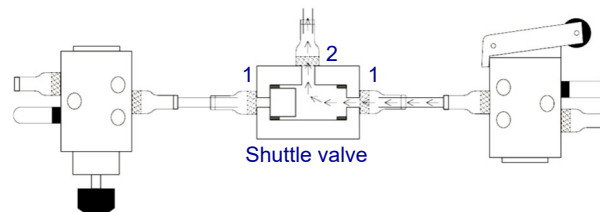
- **Turn the red lever to switch off the air supply.**
- Now add a safety device, to make sure that the door cannot be opened if the vehicle is still moving. This takes the form of a second control valve, operated by the vehicle brake. This valve is operated by a roller, as shown in the diagram.



w3d

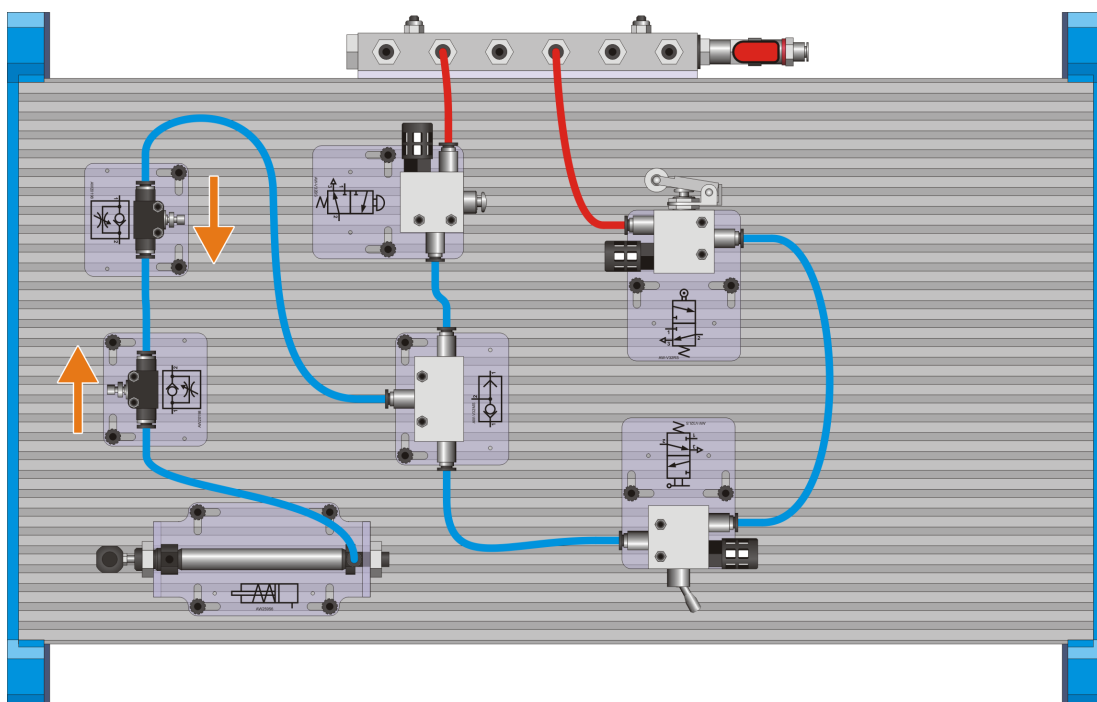
w3c

- Next, add a second switch, so that the door can be opened from inside or outside the vehicle. This requires a new form of control valve called a shuttle valve, which allows two sources of compressed air to operate independently.



w3e

- The full system is shown below.
- Turn on the air supply. Test the system to see if it performs as required.



w3f

# Worksheet 3

## Automatic door

### So what?

#### Types of actuators:

Control valves can be operated by a wide range of different actuators, including:

- lever switches;
- springs;
- foot pedals;
- rollers.

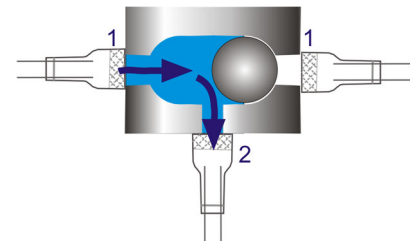
The symbols for a number of actuators are shown below. The symbol is attached to the end of the valve symbol.

#### The shuttle valve:

- consists of a ball inside a cylinder. Air pressure applied to the left-hand port 1, blows the ball to the right, blocking the other port 1, and allowing air to flow out of port 2. When air pressure is applied to the other port 1, the ball is blown to the left, and air from the second source is flows out of port 2.
- equivalent to an 'OR-gate' in electronics;
- also known as the double-check valve.

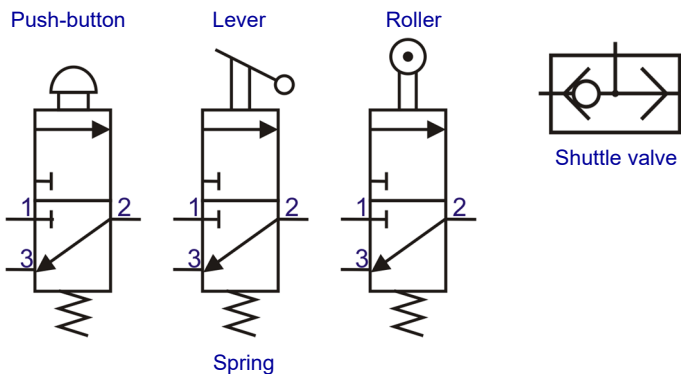


w3g



w3h

#### Symbols:



w3j

w3i

#### For your records:

An object of mass **m** sits on the floor of a building. Its area of contact with the floor is **A**. It exerts a pressure **P** on the floor, because of its weight **W**, (the force pressing down on the floor.)

Copy and complete the following table, by using the formulae given earlier:

Mass of object <b>m</b>	Weight of object <b>W</b>	Area of contact <b>A</b>	Pressure exerted <b>P</b>
3 kg		0.01 m <sup>2</sup>	
	45 N	0.001 m <sup>2</sup>	
	2200 N		11 kPa (= 11000 Pa)
10 kg			150 N

# Worksheet 4

## Push and pull

Some jobs need the piston to push out to move an object. It can return under the action of the spring. That's when a single-acting cylinder is enough.

When you need to both push the piston out and force it back, both using compressed air, then a double-acting cylinder is needed.

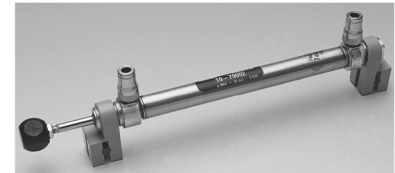
What is the difference?

- Pull out the piston in a single-acting cylinder, and let go, and it flies back in, pushed by the spring. Doing the same with a double-acting cylinder leaves the piston extended.
- Single-acting cylinders have one port - double-acting have two.
- The return force in a single-acting cylinder is fixed - the force of the compressed spring. It may not be big enough to do the job! A double-acting cylinder usually exerts a much bigger return force.



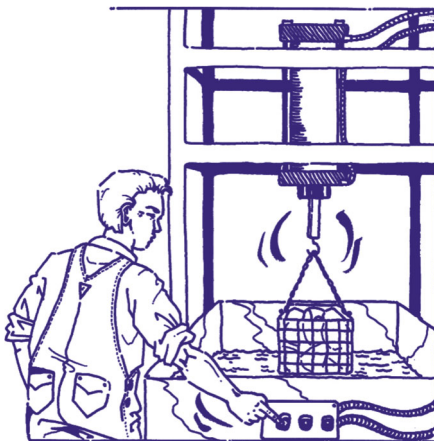
Single-acting cylinder

w4a



Double-acting cylinder

w4b



In a car factory, metal parts are dipped in solvent to remove grease. Could a single acting cylinder raise and lower the basket?

More than likely, the spring wouldn't be strong enough to raise the heavy basket of components after they had been dipped.

The best type of cylinder to use for this job is a double acting cylinder, which uses compressed air to extend the piston and also to retract it.

w4c

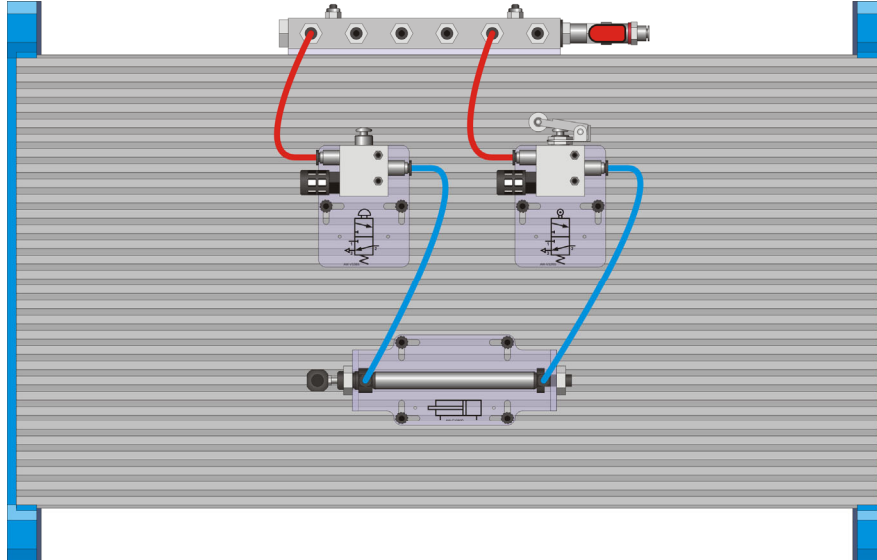
### Over to you:

- **As before, the red lever on the manifold must be off whenever you modify the system.**
- Build the arrangement shown on the next page, using a double-acting cylinder.
- It uses two 3/2 control valves - one to extend the cylinder and the other to retract it.
- Turn on the air supply.
- Press the push-button to extend the cylinder. Notice that nothing happens when you release the valve.
- Next, press the roller on top of the second valve. As air pushes the piston back, air from in front of the piston exhausts from the push-button valve.
- What do you think will happen if you actuate both valves at the same time? Try it!
- Now leave both valves unpressed and try moving the piston. It moves easily because air from either side of the piston can exhaust freely from the unactuated valves.

# Worksheet 4

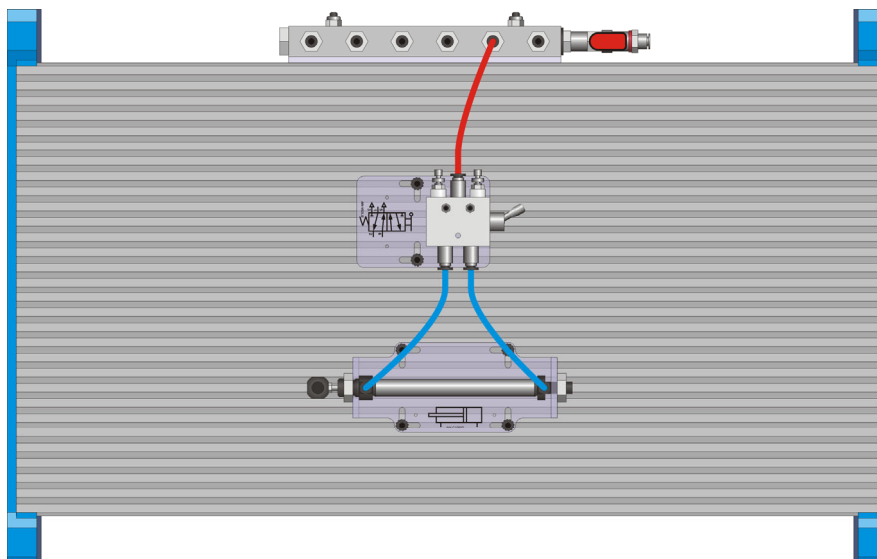
## Push and pull

### Layout for worksheet 4:



w4d

- **Turn the red lever to switch off the air supply.**
- A better way to control the double-acting cylinder is to use a five port valve. Build the circuit shown below, which uses a 5/2 lever operated control valve.
- Turn on the air supply.
- Operate the lever on the five port valve, to check that it can both extend and retract the piston. Can you move the piston rod by hand now?
- The piston rod might move too quickly for the application in hand. You could add flow control valves, but it is simpler to use exhaust restrictors, which screw into the exhaust ports of the control valve. Adjust the screw so that the basket is lowered steadily into the solvent. Then adjust the other exhaust restrictor so that the basket is lifted out at a suitable speed.



w4e

# Worksheet 4

## Push and pull

So what?

### Five port valve:

The improved system for dipping the car components uses a lever operated five port valve, sometimes called a 5/2 valve because it has five ports and two possible states. The one shown here is not fitted with exhaust restrictors.



w4f

w4g

w4h

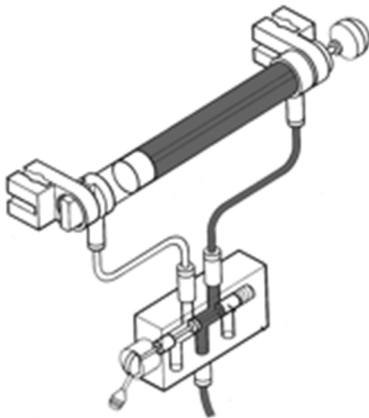
w4i

w4j

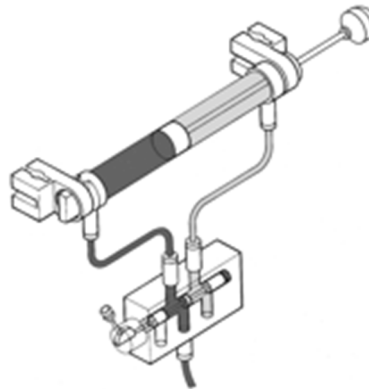
w4k

w4l

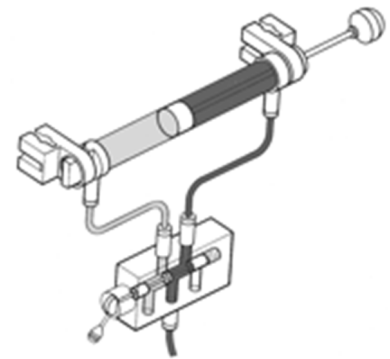
In the first diagram, the spool allows air to flow from the manifold into the front of the cylinder which keeps it retracted.



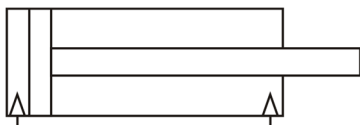
Here, air flows from the manifold into the cylinder to extend it. Air in front of the piston can exhaust through port 3.



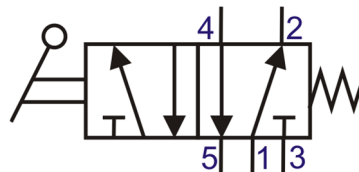
When the valve spring pushes the spool back, air flows from the manifold into the front of the cylinder to retract it. Air behind the piston can exhaust through port 5.



### Symbols:



Double-acting cylinder



Lever operated 5/2 control valve



Exhaust restrictor

### For your records:

- Draw and label the symbols for the following:
  - double-acting cylinder
  - 5/2 roller-operated control valve
  - shuttle valve
  - exhaust restrictor
- Draw the pneumatic circuit diagram for:
  - the final system you set up in worksheet 3
  - the final system you set up in worksheet 4

# Worksheet 5

More for less



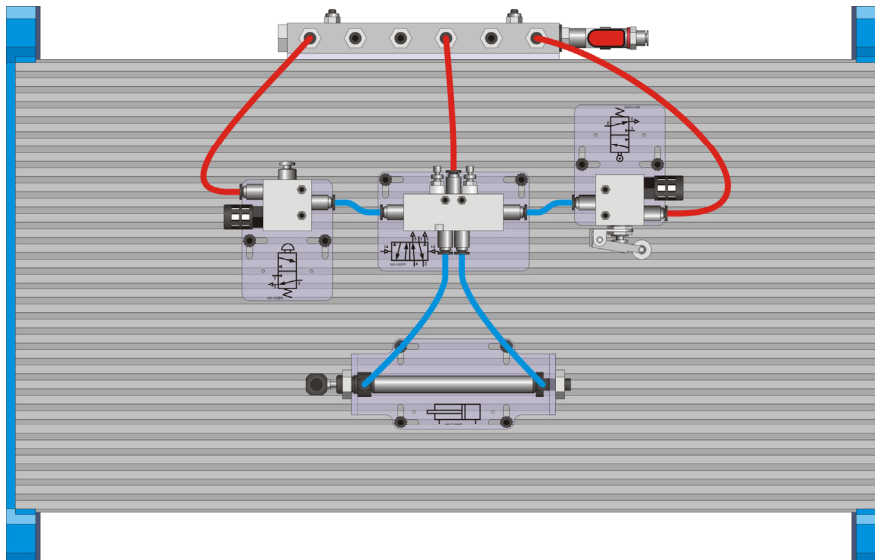
Some applications require considerable force to operate the control valves. Here, a two-stage process, using pilot-operated valves can be used.

In these, the large, main valve is operated by a smaller, low pressure, pilot valve. Usually, both valves are housed in the same unit.

w5a

## Over to you:

- **As usual, the red lever on the manifold must be off whenever you modify the system.**
- The Automatics essentials kit contains a five port valve, inside which the spool is moved from one position to another by compressed air. The two extra ports, one at either end, numbered 12 and 14, are called pilot ports. The valves that control the air to the pilot ports are called pilot valves.
- Build the arrangement shown below. It uses two 3/2 control valves, one push-button operated, one roller operated, as pilot valves.
- Turn on the air supply, and check that the system behaves in the same way as that in the last worksheet.

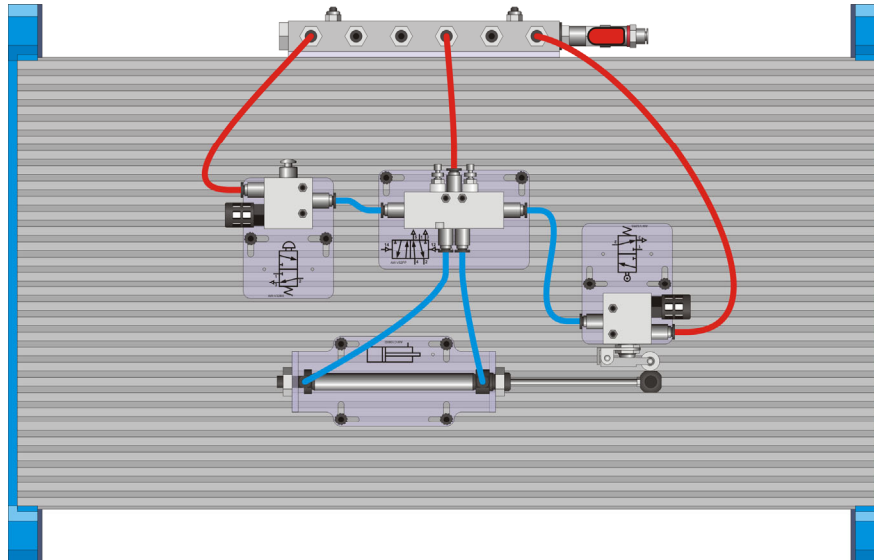


w5b

- By changing the layout of the components, the same system can make the cylinder retract automatically. The new layout is shown on the next page.
- **Turn the red lever to switch off the air supply.**
- Build the new system. Notice that the cylinder has been reversed. Bolt down the the roller operated valve firmly in a position where the fully extended piston rod just presses it down.
- Turn on the air supply, and check that the system behaves as required.

# Worksheet 5

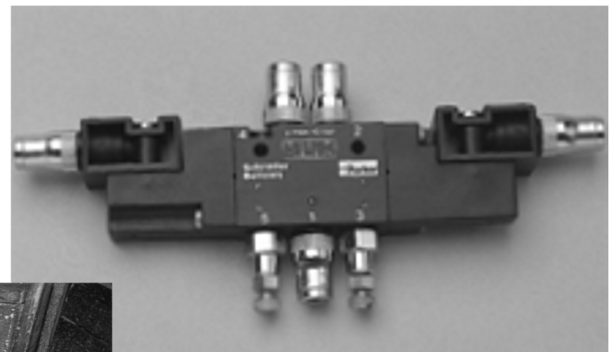
More for less



w5c

- When the system works properly, adjust the exhaust restrictors on the 5/2 valve so that the cylinder extends quickly, but retracts slowly. A system like this could be used to operate an animated figure on a theme park ride. As the vehicle passes, it presses a button. The bandit pops up and then disappears again automatically.

Pneumatically controlled animated bandit figure



w5d

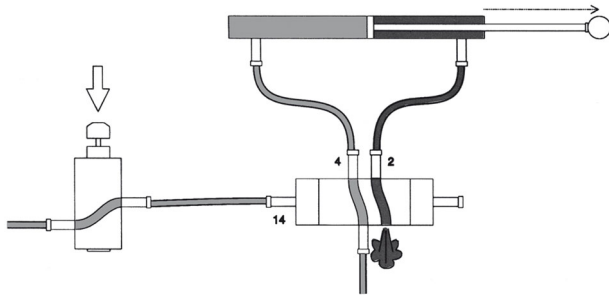
5/2 pilot control valve

w5e

## So what?

### Pilot operated five port valve:

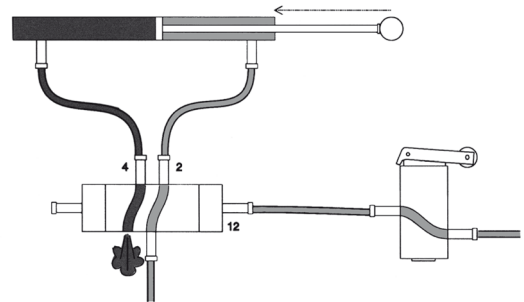
- The Automatics essentials kit contains a type of five port valve that is not operated by a mechanical actuator such as a lever or a button.



The spool inside the valve is moved from one position to another by compressed air. This is called a pilot/pilot five port valve. It has two extra ports, one at either end, called pilot ports and numbered 12 and 14. When air is sent to pilot port 14, the spool is moved to the position shown.

w5f

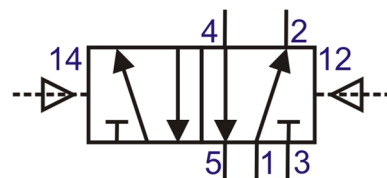
The spool moves into its other position when air is sent to pilot port 12.



w5g

### Symbol:

Pilot pressure lines are normally shown as dotted lines in circuit diagrams.



pilot controlled 5/2 valve

w5h

### For your records:

- Use the details given on this page, and the circuit symbol to describe the operation of the pilot 5/2 valve. Your description should cover all the port numbers given on the circuit symbol.
- Use the internet or equivalent resource to find an example of the use of pilot air controlled pneumatic valves. Explain why it is necessary to use pilot valves in your chosen application.
- Use the internet or equivalent resource to find an application where a pneumatic cylinder uses automatic retraction. Write a short description of the application.

# Worksheet 6

## Animated additions



Theme parks thrive on animatronics figures, that move, breathe fire, roar etc. Our bandit in the last worksheet seems tame by comparison. It leapt up, and sank back slowly.

In this worksheet, we look at two techniques that could improve the performance. One adds a time delay, and the other uses a less intrusive form of triggering, related to the pilot air triggering we saw earlier.

w6a

### Over to you:

- **Make sure that the red lever on the manifold is off whenever you modify the system.**

- The first new device is an air reservoir, a container for compressed air. This is bolted to the platform with short T-bolts in the usual way.

- Build the circuit shown below. It uses a T-connector to create a branch for the reservoir, and a flow control valve, to control the rate at which air flows into the reservoir. The slower the air flow, the longer it takes for pressure to build up in the reservoir, and as a result, the greater the delay.



- Turn on the air supply.

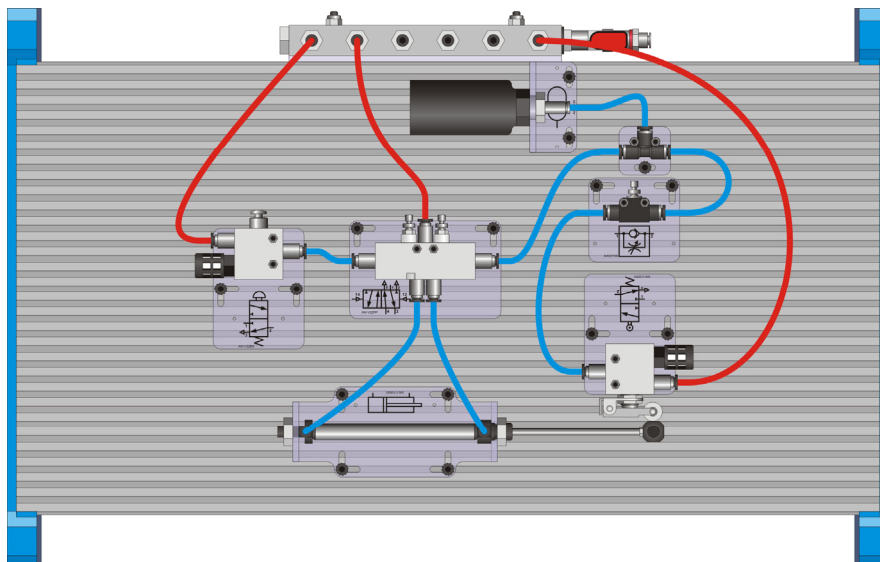
- Screw the flow control valve out to its most open state, and operate the circuit. There will be only a very short delay before the cylinder retracts.

- Screw the flow control valve down completely, and then unscrew it slightly. This will give a much longer time delay.



w6b

w6c



w6d

# Worksheet 6

## Animated additions

### Over to you:

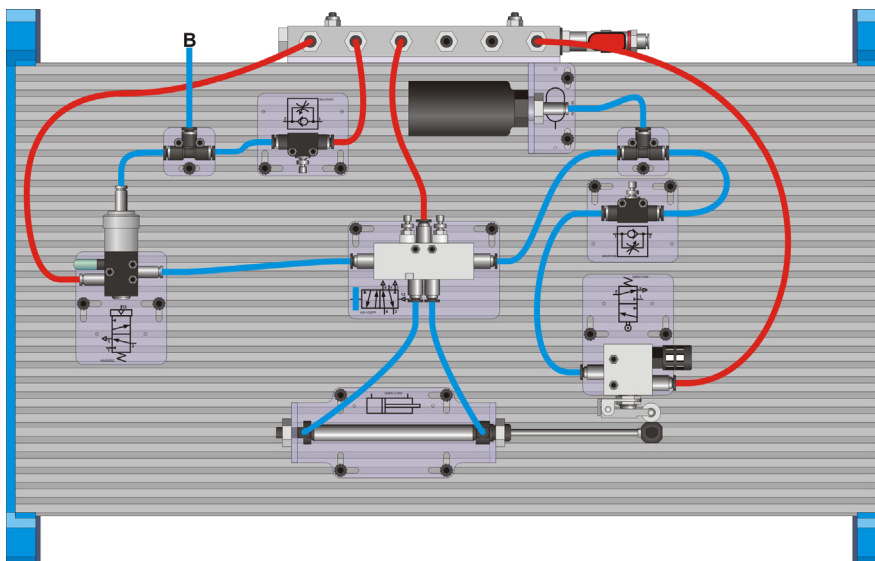
- **Make sure that the red lever on the manifold is off whenever you modify the system.**

- The second device is called a diaphragm valve, or pressure-sensitive valve. The one in the Automatics essentials kit is a normal three port valve, but instead of having a mechanical actuator, it is actuated by a thin sheet of rubber called a diaphragm. This responds to an increase in the air pressure at port 12, the pilot port.



w6e

- Build the circuit shown below. This is called an air-bleed circuit, because air can escape slowly into the atmosphere. A flow control valve determines the rate at which the air bleeds out. Blocking the end of the bleed pipe, **B**, causes the pressure inside to increase. Eventually, this causes the diaphragm valve to actuate.
- Turn on the air supply.
- Test the circuit by blocking the end of the bleed pipe, **B**.  
**IMPORTANT:** Use the end of a pen or pencil to block the pipe. Don't use your finger. Remove the block as soon as the valve responds and extends the cylinder - don't allow too much pressure to build up on the diaphragm.
- How would the train trigger the valve as it passes the figure?
- Experiment with different settings of the flow control valve. If the air is allowed to bleed out quickly, pressure will build up sooner when the pipe is blocked. So, the diaphragm valve will respond more quickly.



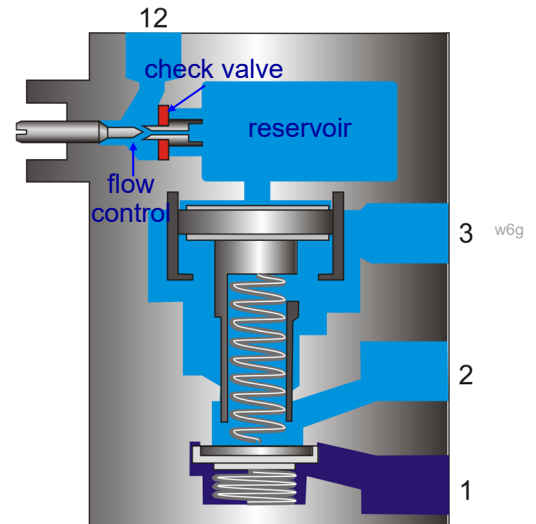
w6f

# Worksheet 6

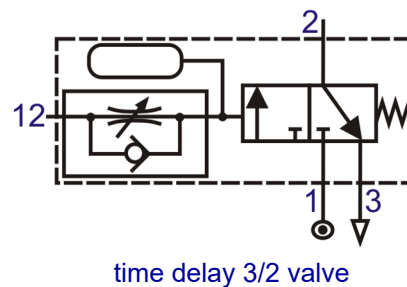
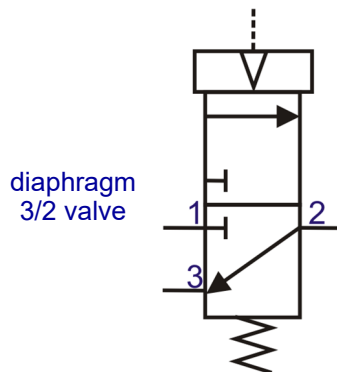
## Animated additions

### So what?

- Both circuits work in the same way:  
In the diaphragm valve, pressure builds up and eventually actuates the diaphragm valve.  
In the time delay circuit, the pressure inside the reservoir builds up slowly until it is high enough to trigger the valve.
- All three components of the time delay circuit, the reservoir, the flow control valve and the control valve itself are often incorporated into the one device, called a time delay valve.
- Time delay valves are operated by pilot air. The time taken for the air pressure to build is variable, set by adjusting the constriction in the flow control valve.
- Time delays are widely used in industrial equipment.  
For example, it may be used to give a tool time to clear the area before moving the work piece.



### Symbol:



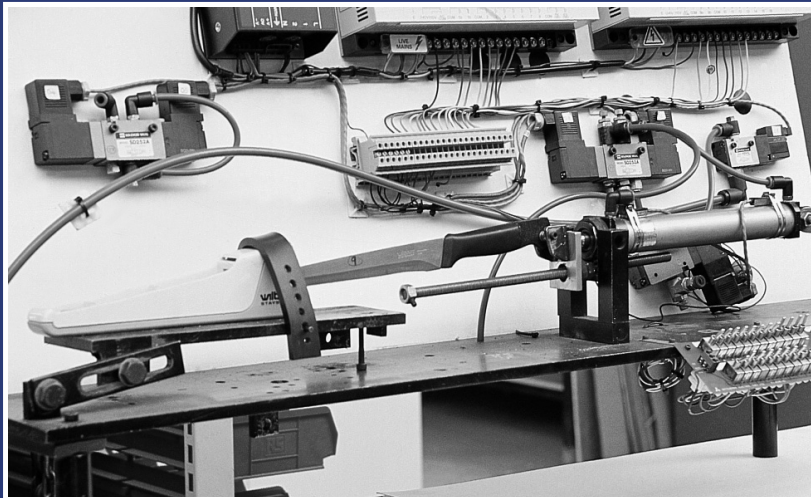
### For your records:

- Draw and label the symbols for the following:
  - pilot controlled 5/2 valve
  - air reservoir
  - diaphragm 3/2 valve
  - time delay 3/2 valve
- Draw the pneumatic circuit diagram for the first system you set up in worksheet 6.
- An automatic door opening system must:
  - be able to be opened from inside or outside by pushing a button;
  - remain open for an adjustable time period;
  - then close automatically;
  - have a means to keep the door open continuously when needed.

Draw a pneumatic circuit diagram for this system.

# Worksheet 7

## Reciprocation, reciprocation, reciprocation



Consumer goods must be 'fit for purpose'. Whether it's a mattress, cupboard hinge or tennis racquet, the manufacturer must test it for performance and durability.

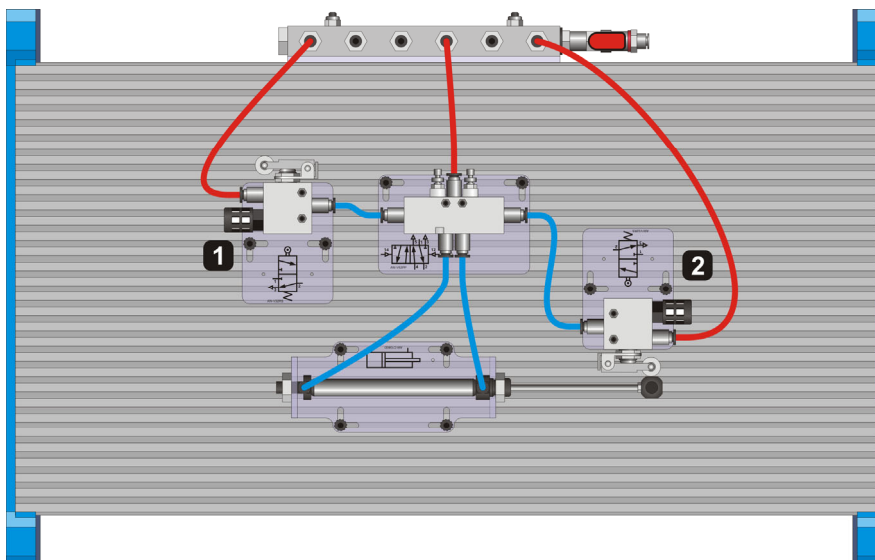
The picture shows a knife-testing rig. The knife is pushed in and out of the knife holder repeatedly to simulate a lifetime of normal use.

Pneumatic circuits offer a controlled way to conduct these endurance tests. What is needed is a system that reproduces the desired movement over and over again - reciprocating motion.

That is the focus of this worksheet.

### Over to you:

- **Make sure that the red lever on the manifold is off whenever you modify the system.**
- Begin by building the automatic return circuit shown below.
- Bolt valve **2** down securely, but don't bolt down valve **1** yet.
- Turn on the air supply.
- Test the circuit by operating the roller on valve **1**.
- Make sure that the piston rod actuates roller valve **2** and returns properly.
- Adjust the exhaust restrictors so that the piston rod moves at a medium speed.

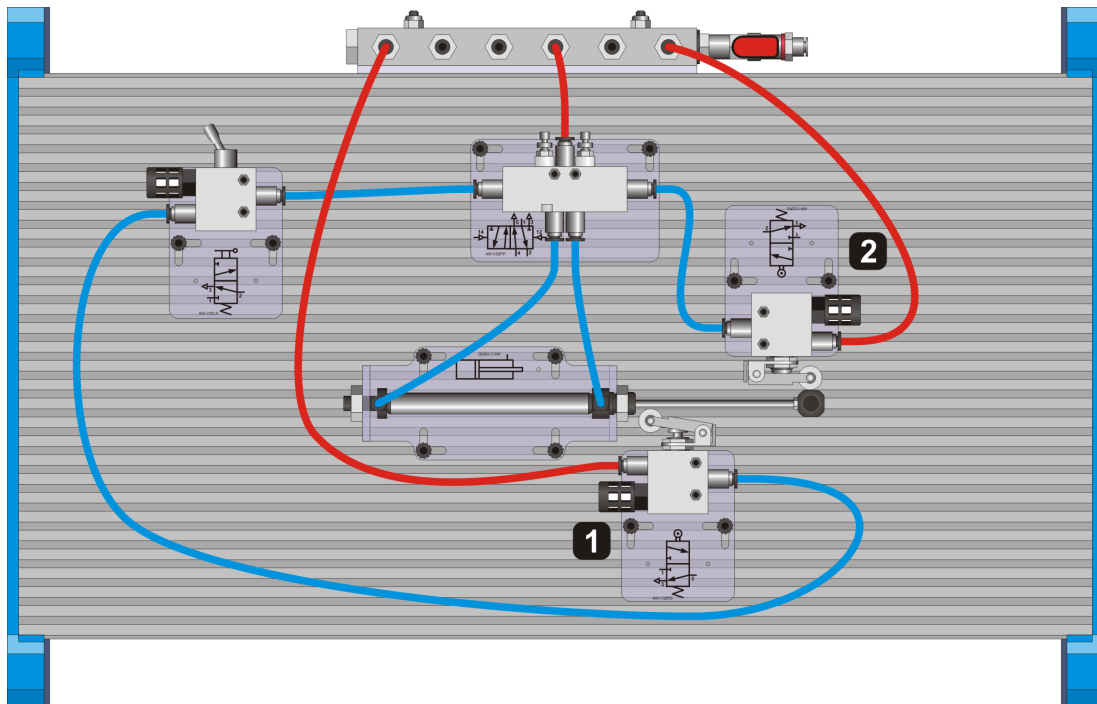


# Worksheet 7

## Reciprocation, reciprocation, reciprocation

### Over to you:

- **Make sure that the red lever on the manifold is off whenever you modify the system.**
- Now, turn off the air supply and build the circuit shown below.
- Position valve **1** so that when the piston rod is fully retracted, it presses the roller down. Then bolt it down securely.
- Turn on the air supply and actuate the lever valve. The piston rod should continue to reciprocate until you stop it with the lever valve.
- Turn off the air supply.
- Now change the position of the lever valve so the circuit will stop with the cylinder extended.
- Turn on the air supply and test your new arrangement.



w7c

### HELP

- If the circuit doesn't work properly, turn off the air supply and check that the two roller valves are securely bolted down in the correct position so that the ball on the piston rod presses the rollers down fully.
- Make sure that, as it extends, the piston rod doesn't keep the roller on valve **1** pressed down.

**Don't try to operate or reposition the roller valves while the air supply is turned on.**

# Worksheet 7

## Reciprocation, reciprocation, reciprocation

### So what?

When the lever valve is closed in the pneumatic circuit shown on the previous page, the following sequence of events takes place:

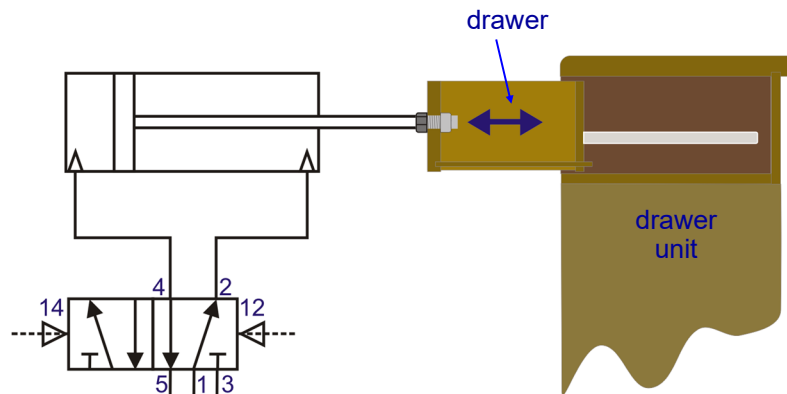
- the cylinder is already retracted, and so valve **1** is actuated by the ball on the piston rod;
- air flows through valve **1** and the lever valve into the pilot 5/2 valve making the cylinder extend;
- as this happens, valve **1** is released;
- eventually, the piston rod actuates valve **2**;
- air flows into the other pilot port of the pilot 5/2 valve, causing the cylinder to retract;
- as this happens, valve **2** is released;
- eventually, the ball on the piston rod actuates valve **1**.

This process repeats until the lever valve is switched off. Then, the piston stops moving when the cylinder is retracted.

### For your records:

- A furniture manufacturer uses a pneumatic test-rig to check for wear-and-tear on drawers in a new drawer unit.

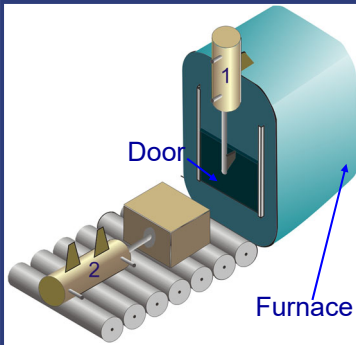
Part of the circuit is shown below. A reciprocating double-acting cylinder opens and closes the drawer repeatedly. However, it is found that the test-rig moves the drawers too rapidly. Suggest how it can be modified to operate more slowly. Copy the pneumatic circuit diagram and complete it to show your modification.



- Which is greater - the force exerted as the cylinder extends, or the force exerted as it retracts? Explain your reasoning.

# Worksheet 8

## In sequence



Often, two or more pneumatic cylinders work in collaboration.

In the case shown, one cylinder opens the furnace door, and then the other pushes the sample inside. The second cylinder retracts, and then the first one closes the door.

Such sequences can be carried out using only pneumatics, or by using electronics to control the pneumatics, as is shown in a later module.

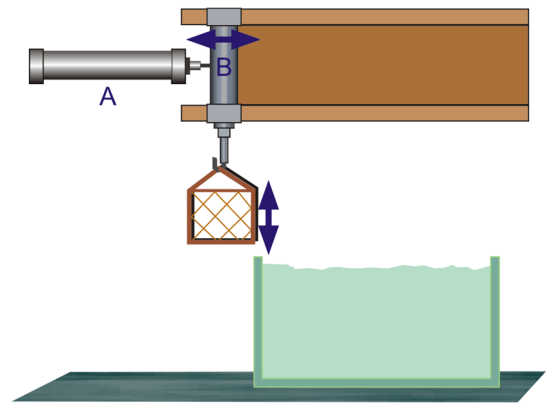
w8a

### Over to you:

The circuit for dipping car components, in Worksheet 4, is improved by using two cylinders in a sequence. The new system, shown here, means that the operator does not have to lean out over the tank.

The sequence is:

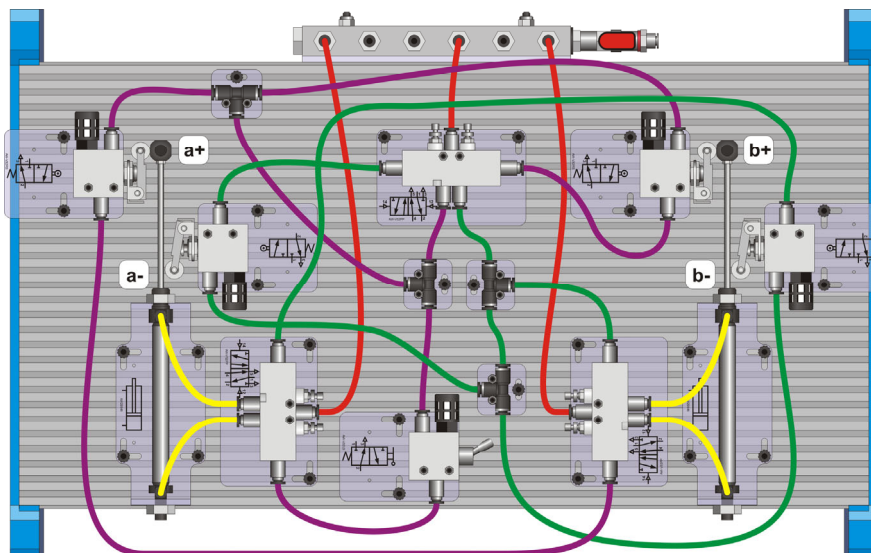
- Cylinder A extends to position the basket over the tank.
- Cylinder B extends to dip the basket.
- Cylinder B retracts to lift the basket out of the tank.
- Cylinder A retracts to bring the basket back to its starting position.



w8b

This sequence can be written as 'A+, B+, B-, A-'

- **Make sure that the red lever on the manifold is off whenever you modify the system.**
- Build the circuit shown below. Take care to check that all connections are made correctly. The colour code highlights the two air supply groups.
- Turn on the air supply.  
Test the system, and use it to work through the explanation given on the next page.



w8c

### Over to you:

The solution is an example of the cascade method for designing sequential control systems.

This divides the air supply to the pilot valves into two groups.

In the diagram on the next page, shown in purple, group I supplies the Start valve and valves a+ and b+.

Group II, shown in green, supplies valves a- and b-.

A pilot/pilot five port valve switches the air supply from one group to the other, half way through the sequence. This valve is called the group changeover valve.

### How the Circuit Works:

1. Switching on the Start valve sends a signal to port 14 of control valve a, extending cylinder A.
2. Cylinder A piston rod then actuates valve a+, sending a signal to port 14 of control valve b. This extends cylinder B.
3. **Changeover:** The next step in the sequence is for cylinder B to retract. This requires a signal at port 12 of control valve b, but this valve is already receiving a conflicting signal at port 14 from pilot valve a+.

The air supply to pilot valve a+ must therefore be removed before the sequence can continue. This is done by changing the air supply from group I to group II.

When cylinder B extends, the signal from pilot valve b+ goes to port 14 of the group changeover valve and this switches the air supply from group I to group II.

4. Following this changeover, a signal is immediately sent to port 12 of control valve b, which retracts cylinder B.
5. The signal from pilot valve b- goes to port 12 of control valve a to retract cylinder A.
6. **Continue or Stop** When cylinder A retracts, it actuates pilot valve a- and a signal is sent to the group changeover valve to switch the air supply back to group I.

As soon as the air supply is switched to group I, a signal is sent through the Start valve to control valve a to extend cylinder A again and so repeat the sequence. The sequence will continue to repeat itself as long as the Start valve is open.

Whenever it is closed, the sequence will stop after cylinder A retracts.

The component dipping system requires just one sequence at a time, so the operator would close the start valve before the sequence ends.

# Worksheet 8

## In sequence

### So what?

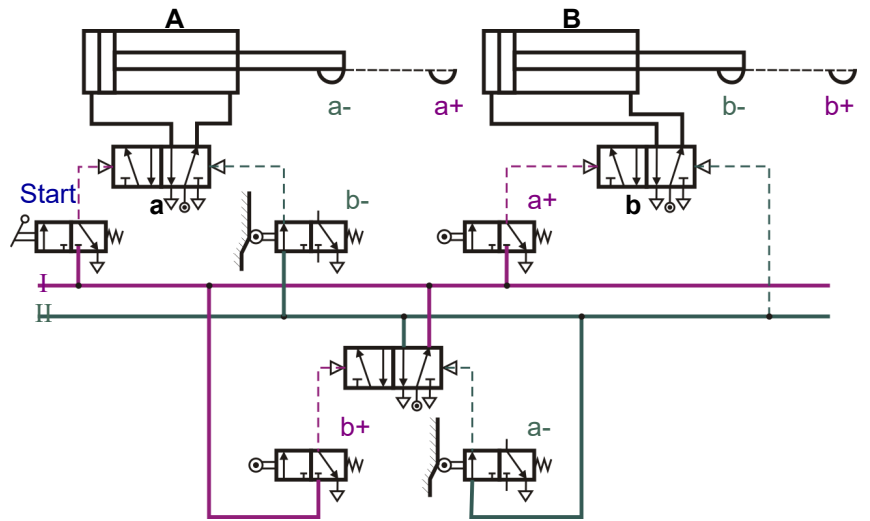
Cascade circuit diagrams would be difficult to follow if drawn like the one earlier, with pilot valves shown in their actual positions.

Instead, they are drawn in a 'virtual' simplified manner.

The one shown opposite is the A+, B+, B-, A- circuit.

The colour coding is the same as that used earlier.

The diagram shows the circuit in its 'off' state.



Group I and II busbars are shown clearly. (A busbar shows all connections linking one port of the group changeover valve to the pilot lines.) Notice the way in which valves a- and b- are shown to be actuated.

### Fault Finding

If your circuit doesn't work properly, follow this procedure:

- Turn off the air supply.
- Check that all pipes are pushed firmly into their fittings.
- Check that the roller valves are securely bolted down and correctly positioned.

The ball on the piston rod should press down the roller firmly when it hits it. The piston rod should also release the roller fully when it moves away.

You may need to adjust the exhaust restrictors on the control valves. The piston rods should move quickly enough to actuate the rollers, but not so quickly that they push the valves out of position.

- Check all piping methodically.  
Work along each busbar, ticking off each correct connection.
- Turn on the air supply and test the circuit again.

### For your records:

- Copy the cascade circuit diagram for the A+, B+, B-, A- sequence, and add an explanation of how the system generates the required sequence.
- Research and then describe an application that requires the sequence A+, A-, B+, B-.
- Draw the cascade circuit diagram for a system that produces the sequence A+, A-, B+, B-.

## About these questions

These questions are designed to be a useful aid to revision.

Allow 25 minutes to answer them and then check your answers with those given on page 31.

For each of the following, choose the correct answer (a, b or c).

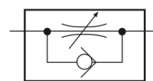
- What is the name of the machine that provides a supply of pressurised air?  
a) condenser    b) compressor    c) contractor
- Which type of movement does a pneumatic cylinder NOT provide?  
a) linear    b) reciprocating    c) rotary
- What should you do first if you notice air escaping from a pneumatic circuit?  
a) tell somebody    b) turn off the air supply    c) panic
- A single acting cylinder is extended by air. How is it retracted?  
a) by a spring    b) by air    c) by gravity
- Air flowing out of a cylinder as it retracts is called:  
a) exhausting air    b) retiring air    c) wasted air
- What is the name of the valve that varies the speed of a piston?  
a) three port valve    b) shuttle valve    c) flow control valve
- Lever, push button, roller are all types of:  
a) valve actor    b) valve actuator    c) valve automator
- Match up each of the valve names in List One to the symbols in List Two.

### List One

- 3 port control valve
- Shuttle valve
- Flow control valve

### List Two

1.



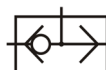
q8a

2.



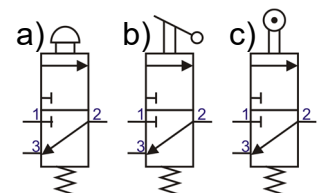
q8b

3.



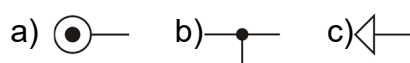
q8c

- Which of the following is operated by a lever switch?



q9

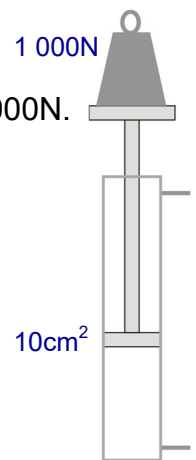
- Which symbol shows that a port is connected to the pressurised air supply?



q10

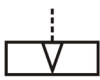
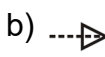

# Revision questions

11. A double acting cylinder is extended by air. How is it retracted?  
a) by a spring    b) by air    c) by gravity
12. Which of the ports on a five port valve is connected to the air supply?  
a) port 1    b) port 2    c) port 3
13. Which one of these ports on a five port valve would have an exhaust restrictor fitted to it?  
a) port 2    b) port 3    c) port 4
14. An automatic return circuit uses:  
a) by-pass valves    b) shuttle valves    c) pilot valves
15. What is the force in N exerted on a piston of area  $0.01 \text{ m}^2$  by air pressure of  $150\,000 \text{ N.m}^{-2}$ ?  
a)  $6.7 \times 10^{-8}$     b) 1 500    c) 15 000 000
16. When air is sent to port 14 of a five port pilot/pilot valve, air flows from port 1 to:  
a) port 4    b) port 3    c) port 2
17. A diaphragm valve is actuated by:  
a) a change in air pressure at port 1  
b) a change in air pressure at port 12  
c) a push-button
18. A vertical cylinder, with a piston area of  $10\text{cm}^2$ , is used to raise a load of 1 000N. When both ports are blocked, the load stops moving. What is then the air pressure, in  $\text{N.cm}^{-2}$ , inside the cylinder?  
a) 0.01    b) 100    c) 10 000
19. Which is the symbol for the actuator on a diaphragm valve?

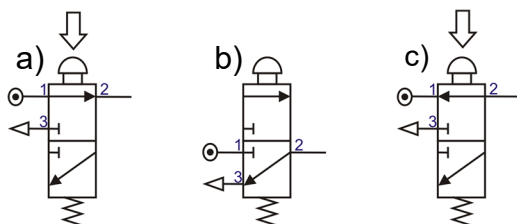


q18

q19

- a)     b)     c) 

20. Which one of the following is the correct symbol for an **actuated** 3 port valve?



q20

Which one of the following is the correct

For each scenario:

- design a pneumatic circuit that could be used to meet the client's requirements.
- make a drawing of the circuit.
- provide notes to explain to the client the purpose of each component you have used.

## 1. Stamping machine:

Remember that the boxes are fragile, and so the stamp should not hit them too hard.

Your design should include a safety guard around all moving parts, and be designed so that the machine cannot operate unless the guard is in place.

### **BURLINGTON** Hand Made Chocolates and Sweets

Dear Designer,

I own a small business which makes expensive, hand-made sweets and chocolates, which are packaged for sale, in cardboard boxes. Each box is individually printed with a price and a "sell-by" date, before it leaves the packaging department. The printing is done by hand, using a self-inking date stamp.

Our problem is that by the end of a shift, the people doing the date-stamping get very tired and bored. This means that the printing becomes very uneven, and the dates are sometimes upside-down or in the wrong place on the box.

We need a stamping machine that will give us the same print every time – and won't get tired!  
Can you please help.

### **The Cottage Loaf Bakery**

Dear Designer,

Could you please help with a problem we are having with our store-room door?

It is very important that we keep the door of our store-room closed as much as possible so that our products are stored at an even temperature. However, the storekeeper has to go in with his arms full of boxes, which makes it difficult for him to open and close the door.

Can you design a pneumatic door-opener that will allow him to open the door by pressing a footswitch on the floor in front of the door. The door must close immediately he has gone through.

Obviously, we don't want the storekeeper to be trapped inside the store-room! So, he needs to be able to open the door either from inside or from outside.

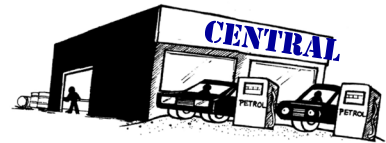
Yours sincerely,

## 2. Storeroom door:

For each scenario:

- design a pneumatic circuit that could be used to meet the client's requirements.
- make a drawing of the circuit.
- provide notes to explain to the client the purpose of each component you have used.

### 3. Forecourt alarm:



d3

I know I'm old-fashioned, but my customers still like me to serve them with petrol. The problem is, that when I'm in the workshop at the back of the garage, I can't tell if a car has driven up to the petrol pumps.

Like all garages, I've got a compressed air line on the garage forecourt. Can you make something that will use the compressed air to sound a bell whenever a car drives up onto the forecourt.

One of my customers said that I need an "air bleed circuit", but that doesn't mean much to me I'm afraid.

### 4. Product testing:

This scenario involves two different pneumatic circuits, *unless you can do it in one!*

#### Ken~Ju Martial Arts Clothing

Ken-Ju (Martial Arts Clothing) Ltd. offers valuable prizes for machines designed to test new types of synthetic cloth for use in martial arts clothing.

The cloth must be tested for:

- 1) **Strength** - when repeatedly stretched and pulled.
- 2) **Resistance to wear** - when subjected to repeated heavy impact and abrasion.

We particularly welcome ideas that use pneumatic power, because our garment making workshops have a ready supply of compressed air for use in our wide range of pneumatically-operated machinery.

Entries must be received at our premises by

## Answers to revision questions (see page 27)

1. b)
2. c)
3. b)
4. a)
5. a)
6. c)
7. b)
8.  $a - 2 / b - 3 / c - 1$
9. b)
10. a)
11. b)
12. a)
13. b)
14. c)
15. b)
16. a)
17. b)
18. b)
19. a)
20. a)

## About this course

### Introduction

This workbook reinforces the learning that takes place in the lecture room for intermediate level courses such as the BTEC National Unit 15: "Electro, Pneumatic and Hydraulic Systems and Devices", providing practical activities and investigations to complement the BTEC syllabus.

The learning aims are to:

- identify industrial pneumatic components, understand how they work, and use them correctly and safely in a range of circuits;
- design and build pneumatic circuits to meet particular needs and opportunities;
- read and draw pneumatic circuit diagrams using CETOP standard symbols;
- calculate force and pressure in pneumatic circuits;
- know how pneumatic systems are used in industry, transport and leisure contexts.

Automatics equipment makes it quick and easy to construct and investigate basic pneumatic circuits, which, thanks to the symbols printed on each component, look exactly like the pneumatic circuit diagram.

### Prior Knowledge

Students require no previous knowledge of pneumatics, but should have reasonable competence in mathematics, and have the study skills required to use these worksheets effectively.

### Learning Objectives

On successful completion of this course the student will have learned to:

- apply six safety rules when building and using pneumatic circuits;
- identify six common applications of pneumatics in industry, transport and leisure;
- list the relative advantages of pneumatic and hydraulic systems;
- identify and use the CETOP symbols for:
  - single and double-acting cylinders, 3 port and 5 port two state control valves, operated by push button, lever switch, roller or pilot air, flow control valves, diaphragm valves, shuttle valves, time delay valves, manifolds, exhaust restrictors, silencers, reservoirs, T-pieces and connecting pipes;
- create and use circuit diagrams for common pneumatic circuits;
- describe the operation of, and relative advantages of single-acting and double-acting cylinders;
- describe the principles of flow-control used in unidirectional and bidirectional flow control valves;
- distinguish between the terms 'mass', 'weight', 'force' and 'pressure', and use formulae linking them;
- describe the structure of, and use, a shuttle valve to isolate two sources of compressed air;
- describe the action of, and use, a 5/2 control valve in operating a double-acting cylinder;
- describe the for of exhaust restrictors for controlling exhaust air speed;
- recognise the need for pilot air operated valves, and use a pilot 5/2 control valve;
- set up an automatic return in a pneumatic circuit;
- set up a variable time delay in a pneumatic circuit;
- describe the structure of, and use, a diaphragm valve to trigger an event in a pneumatic circuit;
- set up a reciprocating pneumatic circuit, and control the speed at which it extends and retracts;
- design a pneumatic circuit to generate a specified sequence;
- create and use cascade circuit diagrams in designing sequential pneumatic circuits.

## What students will need:

The Automatics essentials kit contains the equipment shown in the table.

Qty	Code	Legacy Code	Description
1	AU2140	AW-C1040S	Cylinder, single acting, 10 × 40mm
2	AU2280	AW-C1080D	Cylinder, double-acting, 10 × 80mm
1	AU3200	AW-V32BS	Valve, 3/2, button-spring
1	AU3202	AW-V32LS	Valve, 3/2, lever-spring
4	AU3204	AW-V32RS	Valve, 3/2, roller-spring
1	AU3201	AW-V32DS	Valve, 3/2, diaphragm-spring
1	AU5200	AW-V52LS	Valve, 5/2, lever-spring
3	AU5201	AW-V52PP	Valve, 5/2, pilot-pilot
1	AU3203	AW-V32MS	Valve, mini shuttle
2	AU3022	AW-V22FC	Valve, flow control
1	AU1020	AW-RES45CC	Reservoir, 45 cc
1	AU1040	AW-PLATFORM	Platform
1	AU1010	AW-MANI	Manifold
1	AU1074	AW23122	Tubing, 4mm, red nylon, 5m length
1	AU1065		Permanent fixing kit
1	AU1071	AW23124	Tubing, 4mm, yellow nylon, 30m length
1	AU1072	AW23119	Tubing, 4mm, blue nylon, 30m length
4	AU1030	AW-EQTEE	Junction, equal tee
1	AU1060	AW22876	Tee bolts and sleeves (pack of 50)
1	AU1080	AW-CUTTER	Tube cutting tool.

In addition, a source of compressed air capable of delivering 3 bar of pressure will be required. If you do

Qty	Code	Legacy Code	Description
1	AU1050	AW30100	Compressor

not have this facility on-site, a suitable compressor is available in the Automatics range.

Please note: New product codes for Automatics products were created in January 2015. The “legacy codes” in the tables above refer to the part numbers prior to this date and are included as a convenience for customers who bought products before the part number change.

## Using this course:

It is expected that the worksheets are printed / photocopied, preferably in colour, for the students' use. Students should retain their own copy of the entire workbook.

Worksheets usually contain:

- an introduction to the topic under investigation and its real world applications;
- step-by-step instructions for the practical investigation that follows;
- a section headed 'So What?' which aims both to challenge learners by questioning their understanding of a topic and also provides a useful summary of what has been learned. It can be used to develop ideas and as a trigger for class discussion.
- a section headed 'For Your Records' which provides important summary information that students should retain for future reference.

This format encourages self-study, with students working at a rate that suits their ability. It is for the tutor to monitor that students' understanding is keeping pace with their progress through the worksheets and to provide additional work that will challenge brighter learners. One way to do this is to 'sign off' each worksheet, as a student completes it, and in the process have a brief chat with the learner to assess their grasp of the ideas involved in the exercises that it contains.

A set of multiple choice revision questions has been provided to conclude the work in this unit. These are of mixed difficulty and are designed to help students identify topics which might need more work. It is recommended that students should attempt these questions under examination conditions and without the use of notes or calculators.

Finally, four scenarios are included for students to use as realistic design problems (without solutions, as there are a number of valid approaches to each). These can be used as homework tasks if the instructor so wishes.

## Time:

It will take most students between three and six hours to complete the practical exercises in the worksheets. A similar length of time will be taken up with the 'For your records' assignments, and it is expected that a further, similar length of time will be needed to support the learning in a class, tutorial or in a self-study environment.

Worksheet	Notes for the Tutor	Timing
1	<p>In this, the student's first experience of using the kit, the emphasis is on improving self-confidence and on construction methods.</p> <p>Instructors should check that:</p> <ul style="list-style-type: none"> <li>• correct colours are used for the piping;</li> <li>• pipes are not kinked and of appropriate length;</li> <li>• no air leaks when the air supply is turned on.</li> </ul> <p>The worksheet goes on to contrast hydraulic and pneumatic systems. It is expected that students have some familiarity with hydraulics in order to appreciate the points made here.</p> <p>The conventions used in symbols is introduced, with the push-button 3/2 control valve. It is important that students grasp and can interpret these symbols. Instructors should work through a number of examples of similar symbols, questioning students on their interpretation.</p>	20 - 30 minutes
2	<p>This worksheet starts with a comparison of electrical, hydraulic and pneumatic control systems. The introduction contains three photographs of pneumatic control systems, and instructors should draw the following points from them, by questioning students:</p> <ul style="list-style-type: none"> <li>• 'Pressing cheeses' - pneumatics is relatively 'clean' and is widely used in factories which process foodstuffs;</li> <li>• 'Manipulating timber planks' - electrical control systems involve the risk of sparks and overheating cables. Both would be a potential problem in a timber processing unit. Hydraulic systems can leak hydraulic fluid, which can stain as well as being a health-hazard.</li> <li>• 'Move and clamp operation...' - the cylinder used to clamp is effectively in the stall condition. It must apply pressure to the work piece, without moving it. Electric motors are prone to overheating in this situation. Hydraulic actuators have similar limitations. They use incompressible liquids, pressurised by pumps designed to deliver the liquid at a set rate. In the stall condition, fluid pressure can rise indefinitely, until a pipe or the pump fails.</li> </ul> <p>The worksheet investigates the role of the flow control valve. Instructors need to monitor safety and instil safe practice in the students, still at an early stage in their studies. The structure and operation of these valves is detailed and will need reinforcement.</p> <p>The final section looks at definitions of relevant concepts. In particular, mass and weight are often confused, and instructors should be scrupulous in using these correctly. A huge range of units for pressure are found in the industry, and instructors may wish at this point to introduce the more common, such as the bar.</p>	20 - 30 minutes

Worksheet	Notes for the Tutor	Timing
3	<p>In this worksheet, a common application of pneumatics, the automatic door control system, is developed to incorporate a safety device, and operation from inside and outside. Safe practice is still the major issue.</p> <p>Other forms of valve actuator are mentioned, and the instructor may wish to have examples to hand. (eBay can be a rich and cheap source!)</p> <p>The shuttle valve is introduced, and is described as delivering the 'OR' function. Students not familiar with logic gates, in electronics for example, will need additional information to understand what this means. Its structure and operation is described and may need reinforcement.</p> <p>The session ends with a table to complete, using the formulae given at the end of worksheet 2. With mathematically competent students, the instructor may wish to offer conversions between <math>m^2</math>, <math>cm^2</math> and <math>mm^2</math>, for example, between Pa and bar (1 bar = 100 kPa,) and between <math>Nm^{-2}</math>, <math>Ncm^{-2}</math> and <math>Nmm^{-2}</math>.</p>	20 - 30 minutes
4	<p>This worksheet introduces the double-acting cylinder.</p> <p>With the single-acting cylinder, retraction is controlled by the internal spring. As a result, the force exerted may be too small (or too big,) and cannot easily be varied. In addition, the cylinder must be physically large enough to house the return spring.</p> <p>In the double-acting cylinder, both extension and retraction are controlled by pressurised air, and the return force is usually bigger. However, the double-acting cylinder offers little or no resistance to movement if both air ports are de-pressurised, in a pump fault condition, for example. Although not provided in the Automatics kit, some control valves offer three stages, one of which blocks both valve ports, meaning that the cylinder is then locked in position. The instructor may wish to introduce this refinement at this stage.</p> <p>The worksheet introduce the five port valve as a convenient way to control a double-acting cylinder, and adds exhaust restrictors as a way of controlling piston speed.</p> <p>Finally, the student is asked to draw the pneumatic circuit diagrams for the last two systems constructed. This is to give practice in the use of circuit symbols, and in the abstraction involved in conceptualising circuit diagrams.</p>	20 - 30 minutes

Worksheet	Notes for the Tutor	Timing
5	<p>This worksheet takes the story one step further and looks at the use of pilot air controlled valves. At the core is the link between pressure, force and area. A large force can be generated by low air pressure acting on a piston with a large surface area, or by high air pressure acting on a smaller piston area. The fact is that manual operation may be too difficult when large forces are needed to operate valves. A side effect of using pilot valves is that the double-acting cylinder can be locked in position until pilot air is applied to the opposite pilot port of the control valve.</p> <p>The system is modified so that the movement of the piston closes the valve which controls retraction, resulting in an automatically closing cylinder. - a 'one-shot' circuit. Although this requires careful adjustment, the result is impressive and models a system which has many uses in industry. The student is asked to research some of these at the end of the worksheet.</p>	20 - 30 minutes
6	<p>This adds two refinements to the previous circuit. The first is a variable time delay, using an air reservoir. This is provided as a discrete component in the Automatics essentials kit, but can be incorporated into the body of what is known as a time-delay valve. The idea is that it takes longer for the pressure to rise to the point at which it triggers the pilot valve because of the greater volume created by the air reservoir. The flow control valve limits the flow rate of air into the system, controlling the rate at which the air pressure rises.</p> <p>The second refinement is a more subtle form of triggering, through use of a diaphragm valve, which is set up to detect small changes in air pressure. It works the same way as the 3/2 control valve studied earlier, but has a different actuator. Closely related to the pilot valve introduced in the last worksheet, it is often configured as part of an 'air-bleed' circuit. Here, the pressure cannot rise sufficiently to trigger the valve because it leaks to atmosphere through the bleed pipe. The flow control valve is important here in maintaining system pressure, while still allowing a 'bleed' to atmosphere. In many situations, this arrangement is used to sense the presence of an object, on a conveyor belt for example. The object restricts flow from the bleed pipe, causing the system pressure to rise, triggering the diaphragm valve.</p> <p>The worksheet ends with a design problem for an automatic door. The system is similar to that studied in worksheet 3, with a couple of added twists.</p>	20 - 30 minutes

Worksheet	Notes for the Tutor	Timing
7	<p>This worksheet starts with the automatic return circuit studied in the previous worksheet. It is modified by adding a second roller valve, positioned so that it is actuated when the piston retracts. Overall, the system provides reciprocating motion.</p> <p>It may need careful adjustment of the positions of the two control valves to get it working reliably. It is important that students maintain safe working practice while doing this.</p> <p>The worksheet then steps through the sequence of events, and the instructor should check that students can follow this sequence.</p>	20 - 30 minutes
8	<p>This final worksheet tests students' understanding of the earlier work. It shows that several cylinders and control valves can be combined to produce a sequence of events. This can be controlled using only pneumatic components, as here, or by using electronic control, as shown in the 'Automatics Control' module. One advantage of the method used here is that there is no risk of fire or explosion due to sparks.</p> <p>The 'physical' circuit layout pushes this medium to the limit. There are two double-acting cylinders, three 5/2 pilot valves and five 3/2 valves to pipe up and adjust. The instructor may wish to check the piping before the circuit is activated. Certainly, malfunctioning systems are almost certainly the result of incorrect piping.</p> <p>The second page of the worksheet steps through the stages of the sequence, using what is now standard notation for piston positions. The exercise ends by introducing cascade circuit diagrams, the norm for sequential circuits. Students should be encouraged to work through the sequence on this diagram. The ultimate test of their understanding is the design problem posed at the end, to design the circuit to produce the alternative sequence. This can be set as a class challenge as a timed activity, if that is thought appropriate.</p>	20 - 30 minutes

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03 06 24	small changes to BOM on page 33	