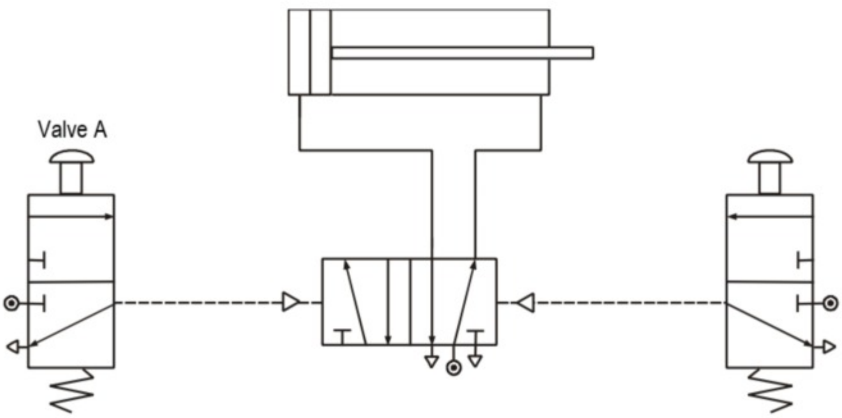
# Higher Engineering Science

# Pneumatics




Name: ______________________

Teacher: ____________________

Class: ______________________

Mrs Gault

## Learning Intentions

- Use of fluid (air) to produce linear movement in single and double acting cylinders
- Standard pneumatic symbols, eg mains air, pilot air, exhaust, t-piece, single and double acting cylinders, 3/2 valve, shuttle valve and actuators (push button, roller, roller trip, plunger, lever, solenoid, spring return and pilot)
- Logic control of pneumatic circuits including OR and AND control circuits
- Symbols and operation of standard pneumatic components (including restrictor, uni-directional restrictor, reservoir, 5/2 valve and actuators (diaphragm, solenoid)
- Pneumatic time delay circuits
- Sequential control systems
- Electro-pneumatic control systems

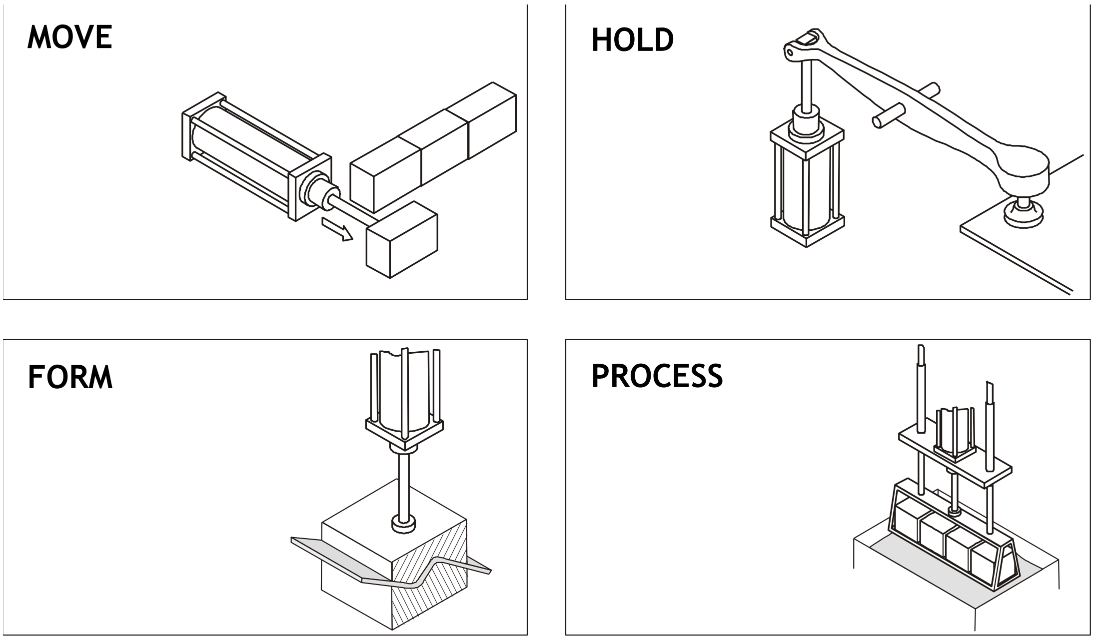
## Success Criteria

- I can design pneumatic circuits using a wide range of actuators and components for different purposes.
- I can create AND and OR control circuits.
- I can create a time delay in a circuit.
- I can create circuits that use sequential control.
- I can create circuits that use electro-pneumatic control.

In this unit we will build on the skills learned in National 5 Engineering Science.

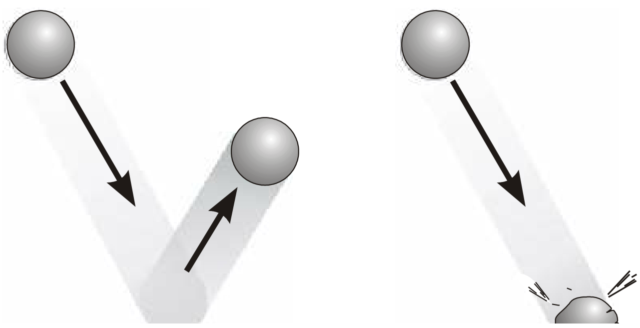
## Introduction

Pneumatic systems make use of compressed air to do work. Pneumatics is used a lot in industry and you would expect to see pneumatic systems in factories, production lines and processing plants. It can be used to do lots of different jobs such as moving, holding or shaping objects.




Every one of these pneumatic systems makes use of *compressed air*. Compressed air is quite simply the air that we breathe forced or squashed into a smaller space. We can use the energy stored in this compressed air to do things.

To understand how compressed air is able to do things, let’s think of a ball. If we blow up the ball so that it is full, it will contain a lot of compressed air. If we bounce the ball, it will bounce very high. However, if the ball is burst then the compressed air will escape and the ball will not bounce as high. Quite simply, the ball bounces because it is using the energy stored in the compressed air.



## Advantages of pneumatics

There are usually lots of different ways to carry out a task, so it is important to understand some of the reasons for choosing pneumatic systems.

### Clean

Pneumatic systems are clean because they use compressed air. We know already that this is just the air we breathe forced into small spaces. If a pneumatic system develops a leak, it will be air that escapes and not oil. This air will not drip or cause a mess and this makes pneumatics suitable for food production lines.

### Safe

Pneumatic systems are very safe compared to other systems. We cannot, for example, use electronics for paint spraying because many electronic components produce sparks and this could cause the paint to catch fire.It is important, however, that we look after and maintain the different components. It is also important that we follow the correct safety rules.

### Reliable

Pneumatic systems are very reliable and can keep working for a long time. Many companies invest in pneumatics because they know they will not have a lot of breakdowns and that the equipment will last for a long time.

### Economical

If we compare pneumatic systems to other systems, we find that they are cheaper to run. This is because the components last for a long time and because we are using compressed air. Many factories already have compressed air for other reasons.

### Flexible

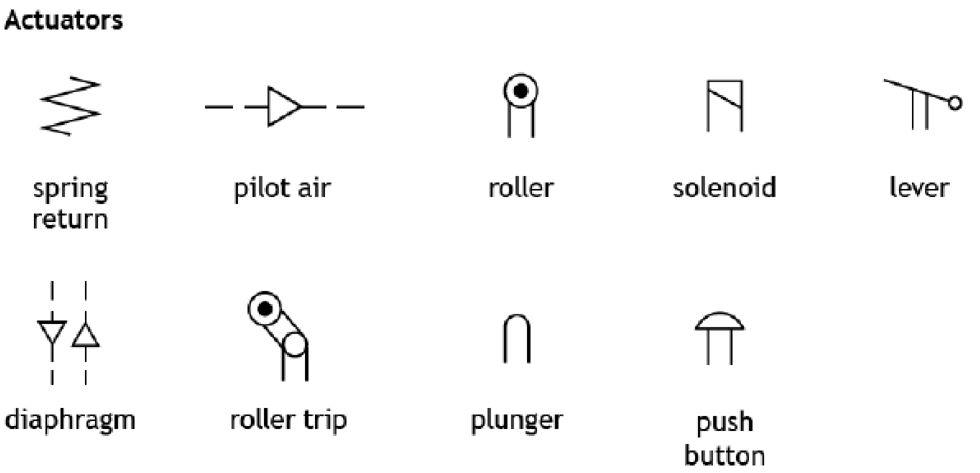
Once you have bought the basic components, you can set them up to carry out different tasks. Pneumatic systems are easy to install and they do not need to be insulated or protected like electronic systems.

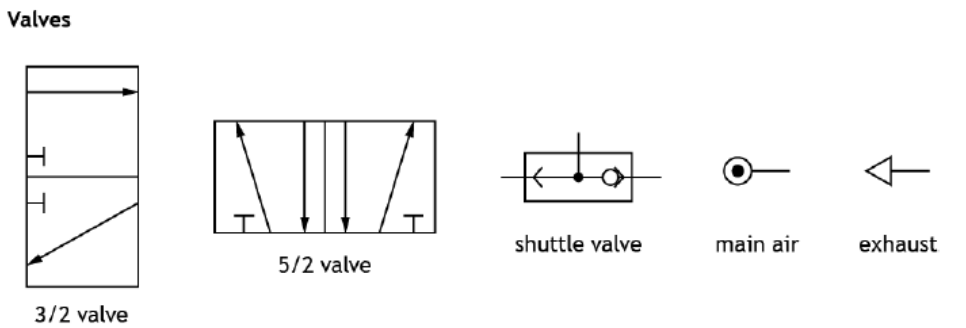
## Safety rules

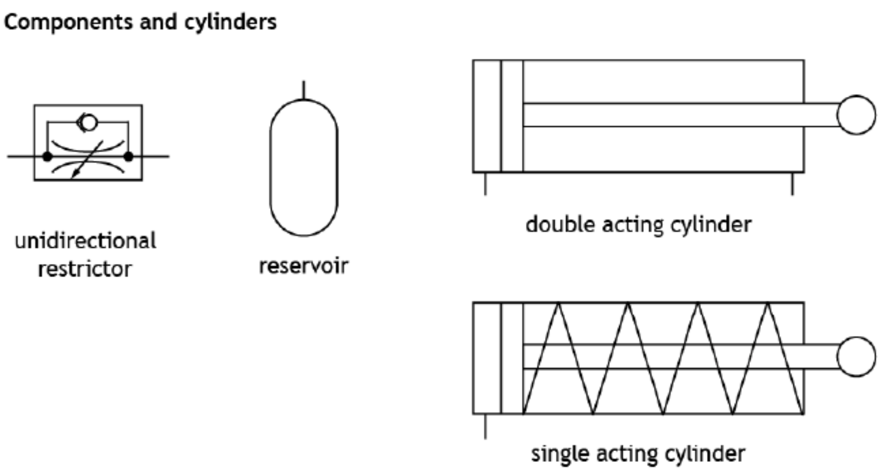
Safety rules help to keep us safe. They highlight dangers and this helps to prevent accidents. When we are using pneumatics we must follow these rules.

1. Never blow compressed air at anyone, not even yourself.
2. Never let compressed air come into contact with your skin, as this can be very dangerous.
3. Always wear safety goggles when you are connecting and operating circuits.
4. Check that all airlines are connected before turning on the main air supply.
5. Always turn off the main air supply before changing a circuit.
6. Keep your hands away from moving parts.
7. Avoid having airlines trailing across the floor or where someone could trip or become entangled.

Pneumatic Components



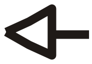



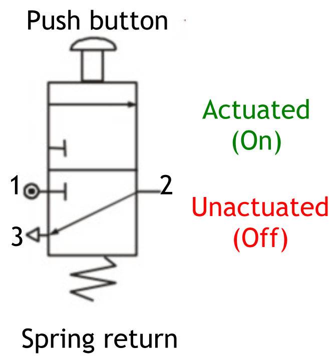
**3/2 Valve**

A 3/2 valve gets its name because it has **3 ports and 2 states**.
The ports are numbered 1-3 in the diagram.

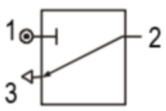
**Port 1** shows **mains air.** 

**Port 2** shows the **output** connection carrying air to another component.

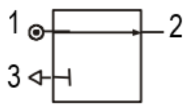
**Port 3** shows where air **exhausts** back to the atmosphere. 




The **states** in the valve are simply **actuated** (on) or **unactuated** (off). The symbol for the valve shows how the valve is operating when in either of its two states:




State 1 - unactuated



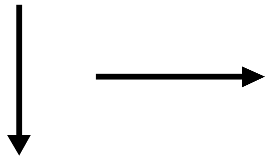

State 2 - actuated

When naming the component you have to state its FULL name. This means you have to state the input actuator, the valve type, and then the actuator that resets the valve.
For example this one would be known as a ‘**Push Button 3/2 Spring Return Valve’.**

## Cylinders

Cylinders are the 'muscles' of pneumatic systems as they are used to move, hold and lift objects. They can even be used to operate other pneumatic components. Cylinders are operated by compressed air and they covert the stored energy in the compressed air into *linear* motion.

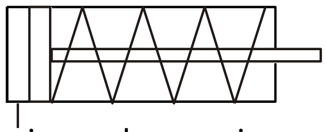
Linear motion is motion in a straight line. We can represent linear motion by arrows like the ones below.



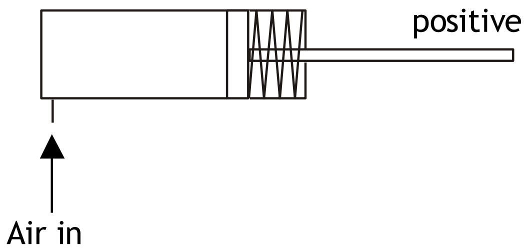
There are two types of cylinder that we will be using: single-acting cylinders and double-acting cylinders.

### Single-acting cylinder

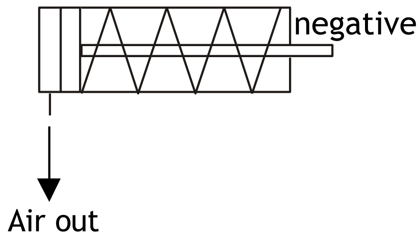
The symbol for a single-acting cylinder is shown below.



A single-acting cylinder requires only one air supply. If we supply compressed air to a single-acting cylinder, the air pushes against the piston inside the cylinder and causes it to *outstroke*. When the piston has fully outstroked it is said to be *positive*.



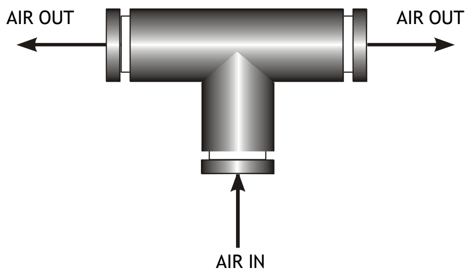

If we stop the supply of air then the spring inside the cylinder causes the piston to *instroke* to its starting position and the piston is said to be *negative*. As this happens, the air inside the cylinder is pushed back out.



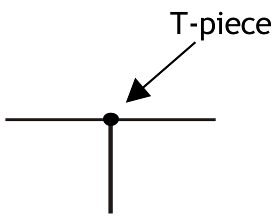

Single-acting cylinders are easy to use and control but they do not produce very big forces. This means that we need to be careful of what we use them for.

### T-piece

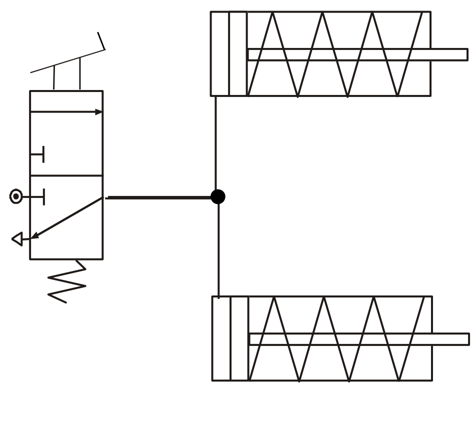
A T-piece or T-connector is a very simple component that lets us split or divide airflow. It can be very useful if you want two cylinders to operate at the same time.




On circuit diagrams, the T-piece is identified by a dot.

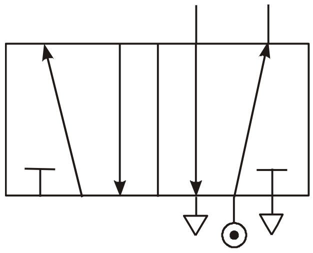



The circuit below shows how a T-piece is use to connect two components to the same valve.



**5/2 Valve**

We have greater control over a double-acting cylinder if we control its outstroke and instroke using a 5/2 valve. This valve has five ports and two states of operation. The ports are always numbered in the same way and the valve is shown in the negative (off) position as shown.



**Port 1 – main air**

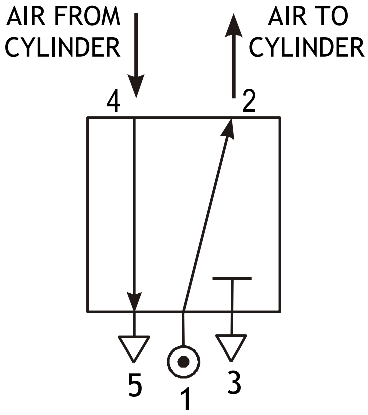
**Port 2 & 4 – output connection**

**Port 3 & 5 – exhaust**

**State 1 - instroke (right hand side of valve)**

In this state, the main air flows through the valve from port 1 to port 2. Any air within the cylinder is able to exhaust through the valve from port 4 to port 5. In this state, a 5/2 valve will cause a double-acting cylinder to instroke or hold the piston in the negative position. This means that air is always being supplied to the cylinder.

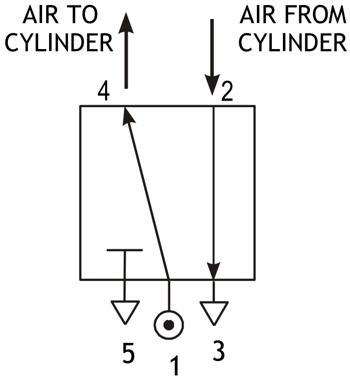
Study the symbol below and ensure that you understand how the air flows through the valve.




**State 2 – outstroke (left hand side of valve)**

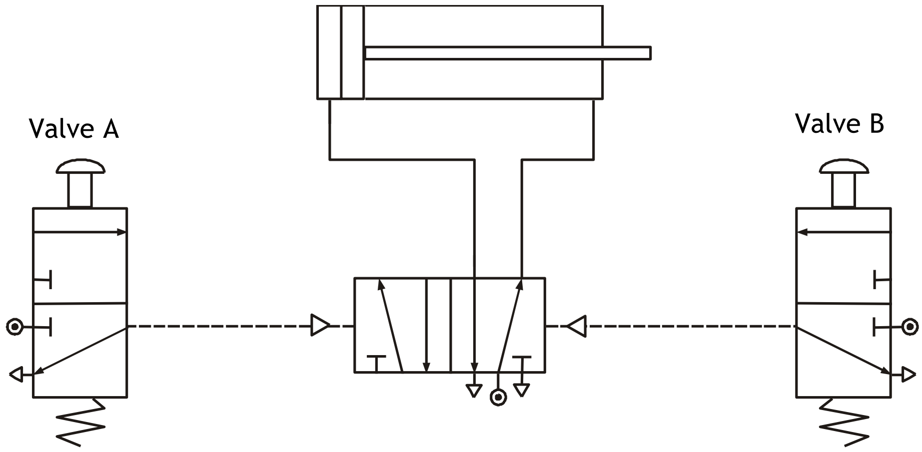
In this state, the main air flows through the valve from port 1 to port 4. Any air on the other side of the piston is able to exhaust through the valve from port 2 to port 3. In this state, a 5/2 valve will cause a double-acting cylinder to outstroke and will hold it in the positive position.

Study the symbol below and ensure that you understand how the air flows through the valve.



**Pilot air**

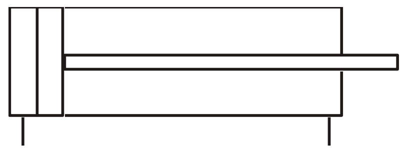
5/2 valves can be operated or actuated in the same way as 3/2 valves. However, the most common way of actuating a 5/2 valve is by *pilot air*. A pilot air 5/2 valve will change state when a brief air signal acts at either end of the valve. This signal is most often supplied from a 3/2 valve. In the example shown below, the button on valve A only needs to be pressed for a moment in order to change the state of the 5/2 valve. The 5/2 valve supplies the double-acting cylinder with air to make it outstroke.




Notice that the pilot airlines to the 5/2 valve are drawn as broken or dashed lines to distinguish them from the other air lines in the circuit.

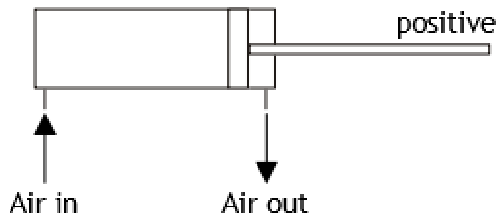
**Double-acting cylinder**

The symbol for a double-acting cylinder is shown below.

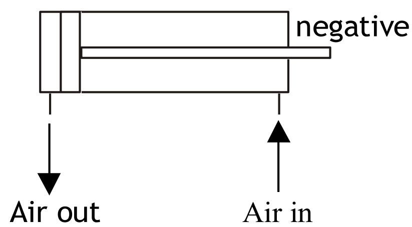


A double-acting cylinder has no spring inside to return it to its original position. It needs two air supplies, one to *outstroke* the piston and the other to *instroke* the piston.

To outstroke a double-acting cylinder we need compressed air to push against the piston inside the cylinder. As this happens, any air on the other side of the piston is forced out. This causes the double-acting cylinder to *outstroke*. When the piston has fully outstroked it is said to be *positive*.




To instroke a double-acting cylinder we need to reverse this action. We supply the compressed air to the other side of the piston. As the air pushes the piston back to its original position, any air on the other side is again forced out. This causes the piston to *instroke* and it is said to be *negative*.

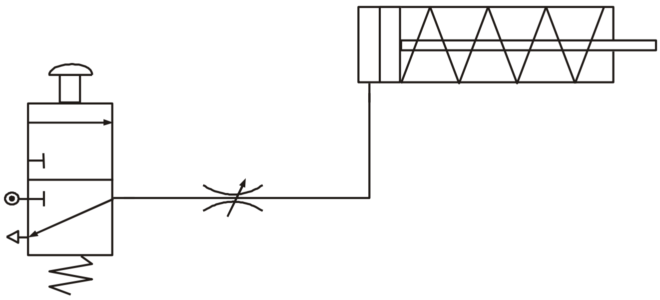



Double-acting cylinders are used more often in pneumatic systems than single-acting cylinders. They are able to produce bigger forces and we can make use of the outstroke and instroke for pushing and pulling.

## Flow control valves

To slow down the speed of a piston we use a *flow control valve*. There are two types of flow control valve available to us. The first type is called a *restrictor* (or sometimes a throttle valve). This valve works by reducing the amount of space that the air can flow through. We can adjust the airflow by turning the small screw on top of the valve.

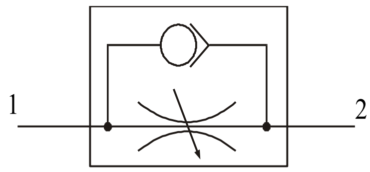
This restrictor slows down the flow of air in both directions. This means that using only one extra component can slow both the outstroke and instroke of a cylinder.In the circuit shown below, the restrictor is used to slow down the speed of the single-acting cylinder. We can adjust this speed by turning the small screw on the top of the restrictor.



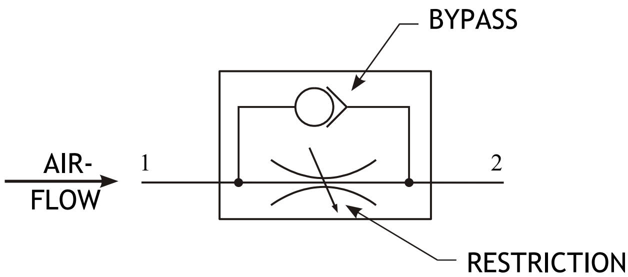
The problem with this type of restrictor is that it always slows down the speed of the piston in both directions. In many cases, we would only want either the outstroke or the instroke to be slowed down. Also, if we study the piston movement very carefully, we sometimes find that it is quite jerky and not smooth as we would want it to be.

### Unidirectional restrictor

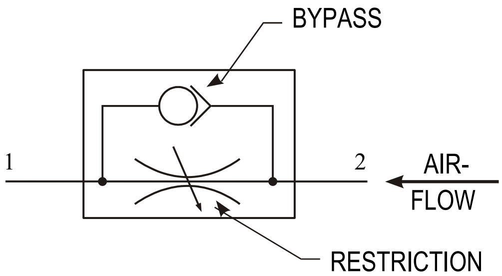
To solve these problems we can use a component called a *unidirectional restrictor*. As its name suggests, it only slows down the air in one direction.



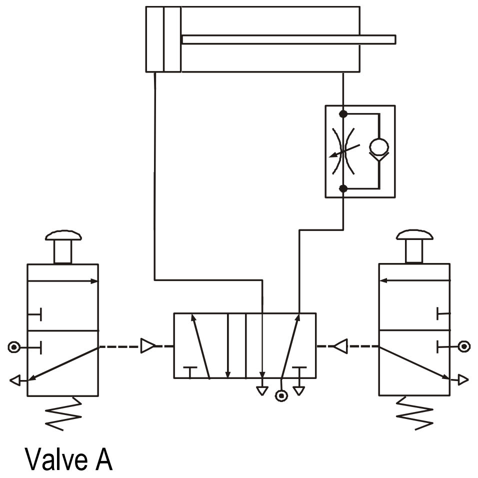

When air flows into port 1 of the restrictor, some of the air takes the bypass route. A small ball is blown against a valve and blocks this path. The air is then forced to go through the restriction and this slows down the airflow.




When air flows into port 2 of the restrictor, again some of the air takes the bypass route. This time, the ball is blown away from the valve and the air passes through unrestricted.



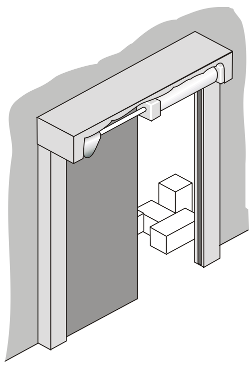

In pneumatics, unidirectional restrictors are much more useful to us. However, we must always be careful to insert them in the circuit the correct way round.



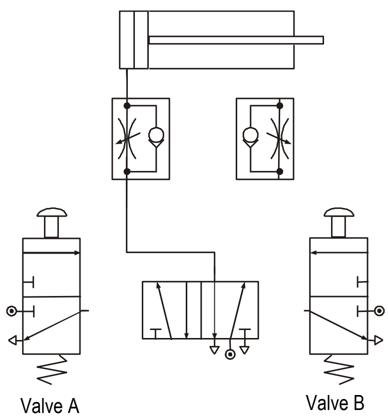

Study this circuit and take note of the position of the unidirectional restrictor. Is it where you expected? The restrictor is placed so that it slows down the *exhaust* air coming from the cylinder. When valve A is pressed, the 5/2 valve changes state and starts to supply the cylinder with air to make it outstroke. Air trapped on the other side of the piston escapes through the restrictor slowly. This makes the piston outstroke slowly.

*We always restrict the exhaust air coming from a cylinder as this makes the piston move much more smoothly.*

**Task 1**
For safety reasons, the entrance door to a storeroom in a supermarket must open and close slowly. A double-acting cylinder is used to slide the door.

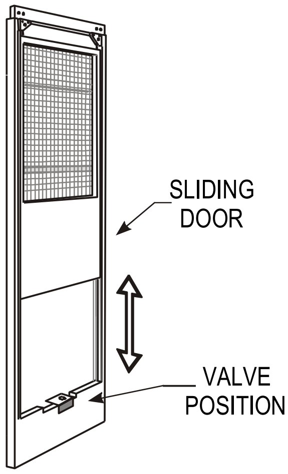


A simplified circuit diagram is shown with some of the piping missing.
(a) Complete the diagram.
(b) Build and test the circuit.
(c) Explain why two restrictors are needed in this circuit.

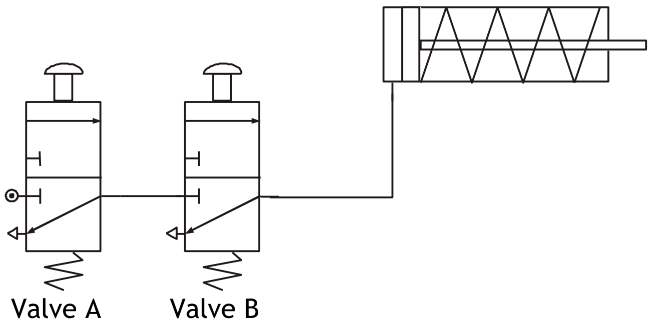


**AND control**

Although pneumatic circuits are very safe, it is important to take safety precautions. AND control circuits can be used to help prevent accidents by ensuring that guards are in position before machines are switched on. These circuits can also be used to stop a machine being switched on accidentally or to stop operators placing their hands in the machine when it is running.




AND control involves connecting 3/2 valves together in *series*. This means that the output from one valve becomes the input to another. Study the diagram below.

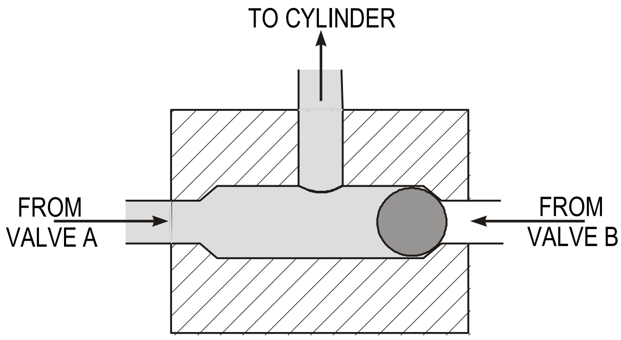



The single-acting cylinder will only outstroke when valve A *and* valve B are pressed at the same time. When the button on valve A is pressed, main air passes through and reaches valve B. The air cannot flow any further until valve B is pressed. This then supplies the cylinder with air and it outstrokes.

**OR control**

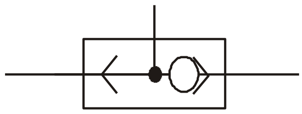
Sometimes we need to control a pneumatic circuit from more than one position. This can be done using OR control circuits. These circuits are quite simple but they need another component called a *shuttle valve*.

A shuttle valve is used to change the direction of air in a circuit. It has a small ball inside that gets blown from side to side. A picture is shown below.

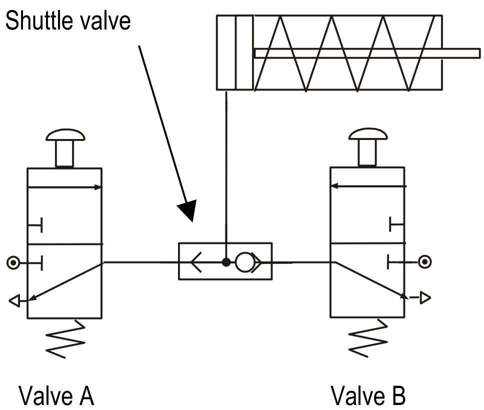



When air is supplied from valve A, the ball gets blown across and the air is directed towards the cylinder. When air is supplied from valve B, the ball is blown to the other side and again the air flows into the cylinder. If air comes from both directions, air still manages to reach the cylinder, as this is the only path it can take.

The symbol for a shuttle valve is shown below.

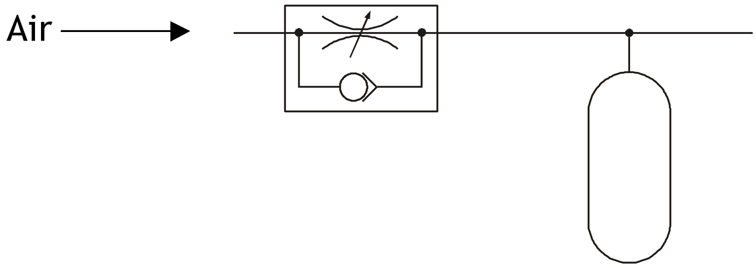


OR control involves connecting 3/2 valves together in *parallel*. This means that either valve will outstroke the cylinder. Study the diagram below.



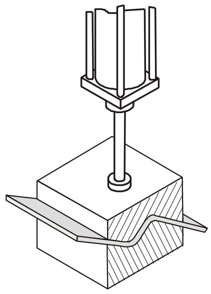
**Time delay**
Sometimes in a circuit we want a pause or delay before something else happens. To create a delay we need to use two components – a unidirectional restrictor and a reservoir.

A reservoir is simply an empty container, just like an empty bottle. The bigger the reservoir, the longer it takes to fill up with air. To make the delay longer we use a unidirectional restrictor in front of the reservoir. This slows down the air so that the reservoir takes even longer to fill. The length of time it takes to fill creates the delay.

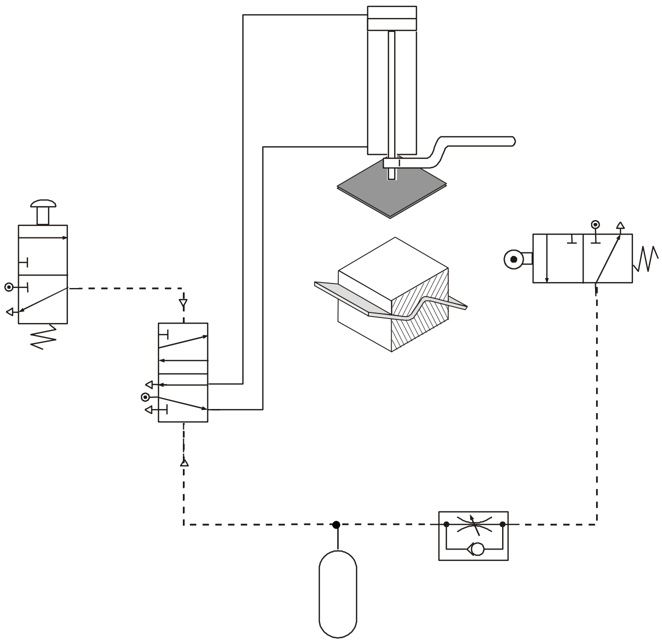



We can change the length of a delay by changing the size of the reservoir or adjusting the restrictor.

Time delays can be very useful in clamping operations when objects need to be held in place by a cylinder for a specific amount of time to glue or set.



In this type of example the delay has to occur before the cylinder would instroke. Study the circuit diagram.

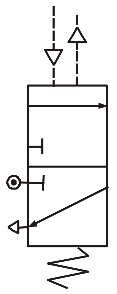


When the push button is pressed, the 5/2 valve changes state and the cylinder outstrokes. As it outstrokes, it pushes the former together and the hot plastic sheet is pressed into shape. As this happens it also actuates the roller. Air now flows through the restrictor and starts to fill up the reservoir. Once the reservoir is full, the 5/2 valve changes state and the cylinder instrokes, ready for the process to begin again.

**Air bleed**

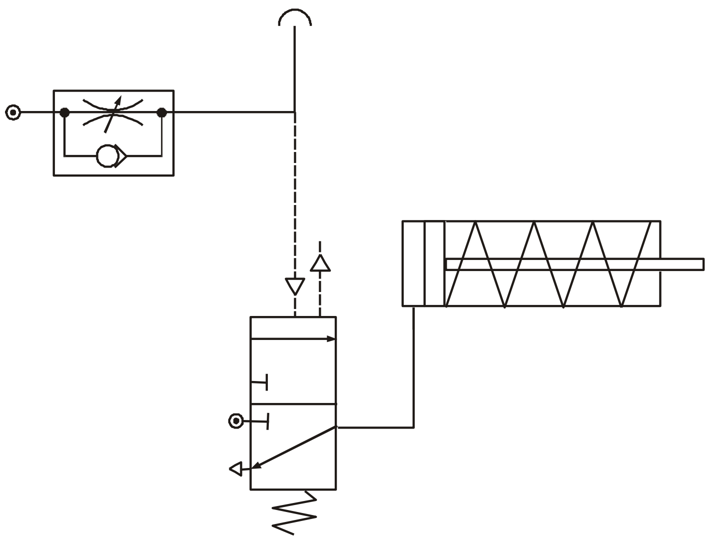
Sometimes with pneumatics we find that the actuators on valves can get in the way of the circuit. Also, some actuators need a big force to make them work and this is not always possible. There are different ways to overcome these problems and one of the most common is to use an *air bleed.*

An air bleed is simply an open pipe that allows the air in the circuit to escape. This air must be at a low pressure, otherwise the pipe would 'wave' about and be dangerous. Air bleed circuits rely on a component called a *diaphragm valve*. This valve is capable of detecting small changes in air pressure. The valve works in the same way as other 3/2 valves; it is only the actuator that is new to us. The symbol is shown below.



The diaphragm is a piece of rubber stretched inside the valve. When air flows into the top of the valve, the rubber expands much in the same way as when a balloon is blown up. When the diaphragm expands, it presses down inside the valve and changes its state.

The signal to the diaphragm comes from an air bleed. When the air bleed is blocked, air is diverted back towards the diaphragm. This actuates the 3/2 valve and the cylinder outstrokes. Notice that the airflow to the air bleed passes through a restrictor. This slows down the air before it is allowed to escape.

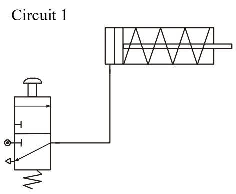


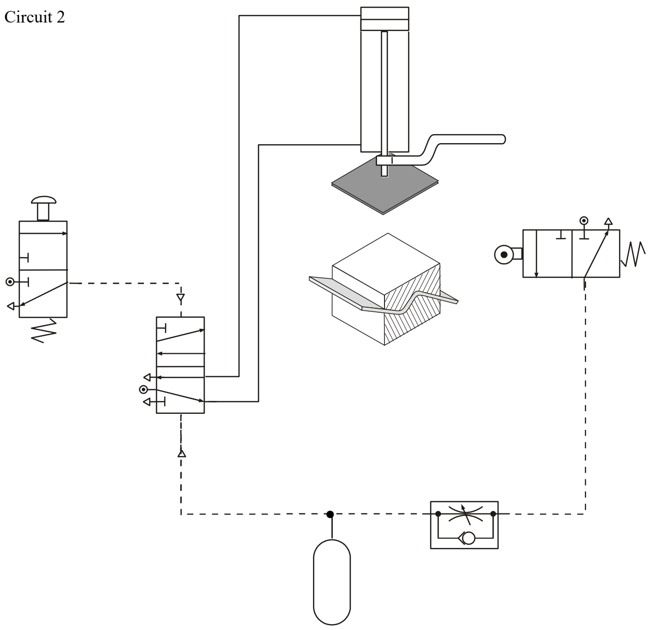
# Automatic circuits

Automatic circuits are commonly found on production lines. They help to speed up production and make sure that the goods are all manufactured to the same standard. There are two types of automatic circuit: semi-automatic and fully automatic.

## Semi-automatic

A semi-automatic circuit is one that completes a process once it has been started, usually by a human operator. We have come across semi-automatic circuits already in the course. You should recognise the two circuits shown below.

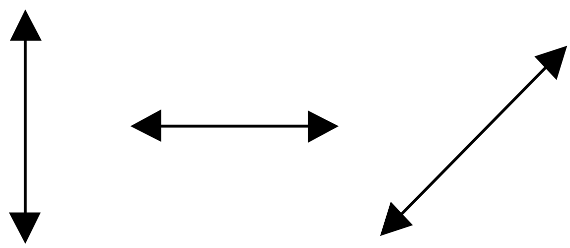


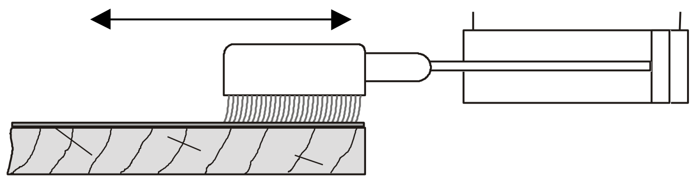



**Fully automatic**

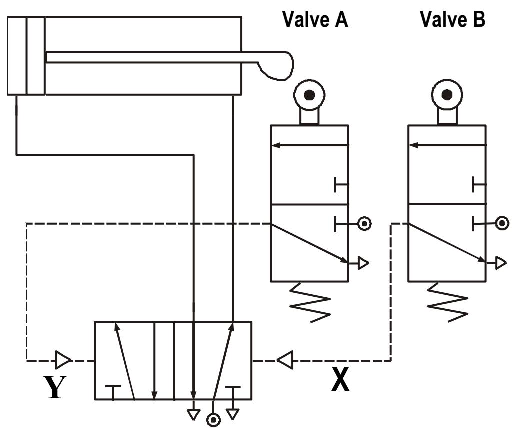
A fully automatic circuit is one that continues to work, performing a task over and over again. It does not stop or wait for input from an operator. These circuits make use of actuators such as a roller trip and plunger to detect the position of the piston as it instrokes and outstrokes.

Automatic circuits produce reciprocating motion. This is motion up and down like the needle on a sewing machine. It can also be left and right, or forwards and backwards along a straight line. We can represent reciprocating motion by arrows like these: For example, a polishing machine requires the reciprocating motion of a double-acting cylinder.

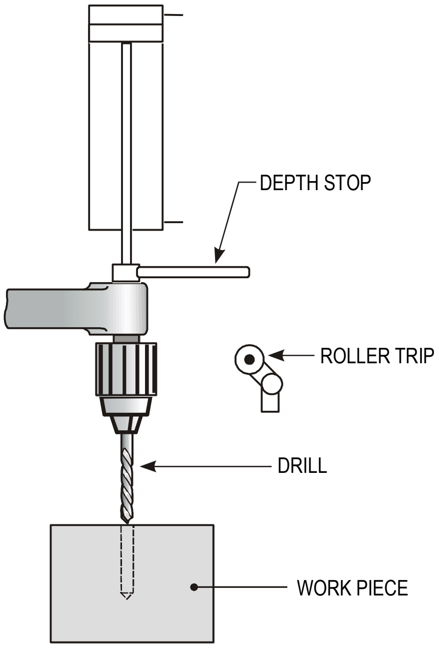




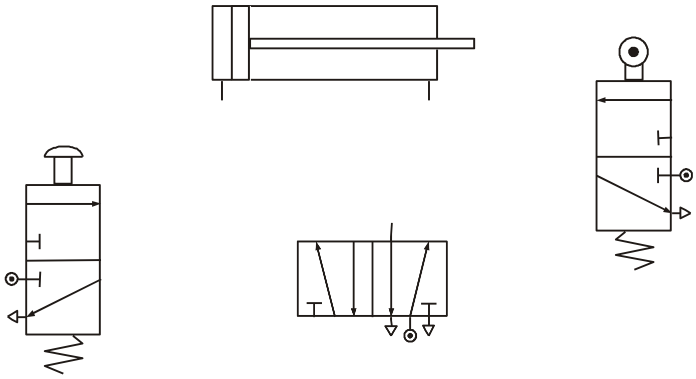
The pneumatic circuit is shown below.




As the piston instrokes, it trips valve A and the 5/2 valve changes state and the piston is sent positive. When it is fully outstroked, it trips valve B and the 5/2 valve returns to its original position, allowing the piston to instroke. The process begins all over again and continues to operate.




A layout of all the components needed is shown with the piping missing.

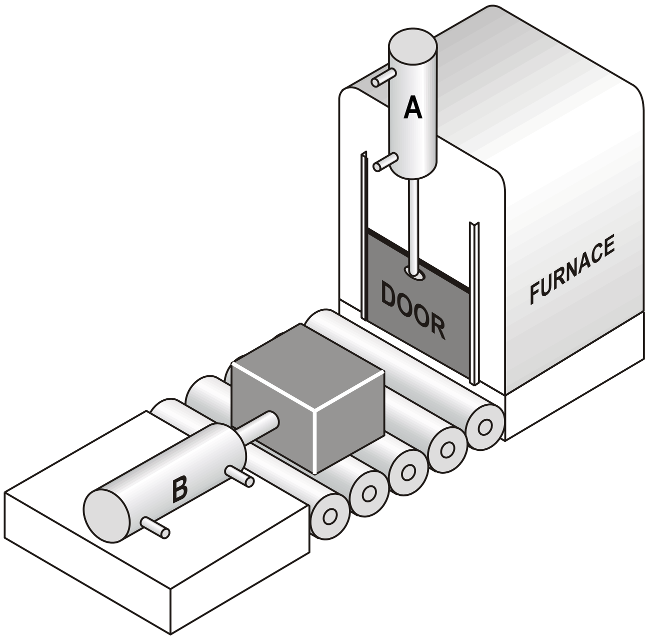


(a) Complete the diagram.
(b) Name each component.
(c) Build and test your solution.
(d) The cylinder outstrokes far too quickly and the drill bits keep breaking. Alter the circuit so that the cylinder outstrokes slowly.

## Sequential control

Many pneumatic systems and machines are designed to perform a range of tasks in a certain order or sequence. This usually involves the use of two or more cylinders working together to complete the task.

For example, a company has automated its production line that involves metal blocks being placed in a furnace for heat treatment. One cylinder is used to open the furnace door and another pushes the metal blocks into the furnace.




The sequence of operations for this process is as follows.

(a) An operator pushes a button to start the process.
(b) The furnace door is opened.
(c) The block is pushed into the furnace and the piston instrokes.
(d) The furnace door is closed.
(e) The sequence stops.

For this system to work successfully, we need to fully understand the order and movement of cylinders A and B.

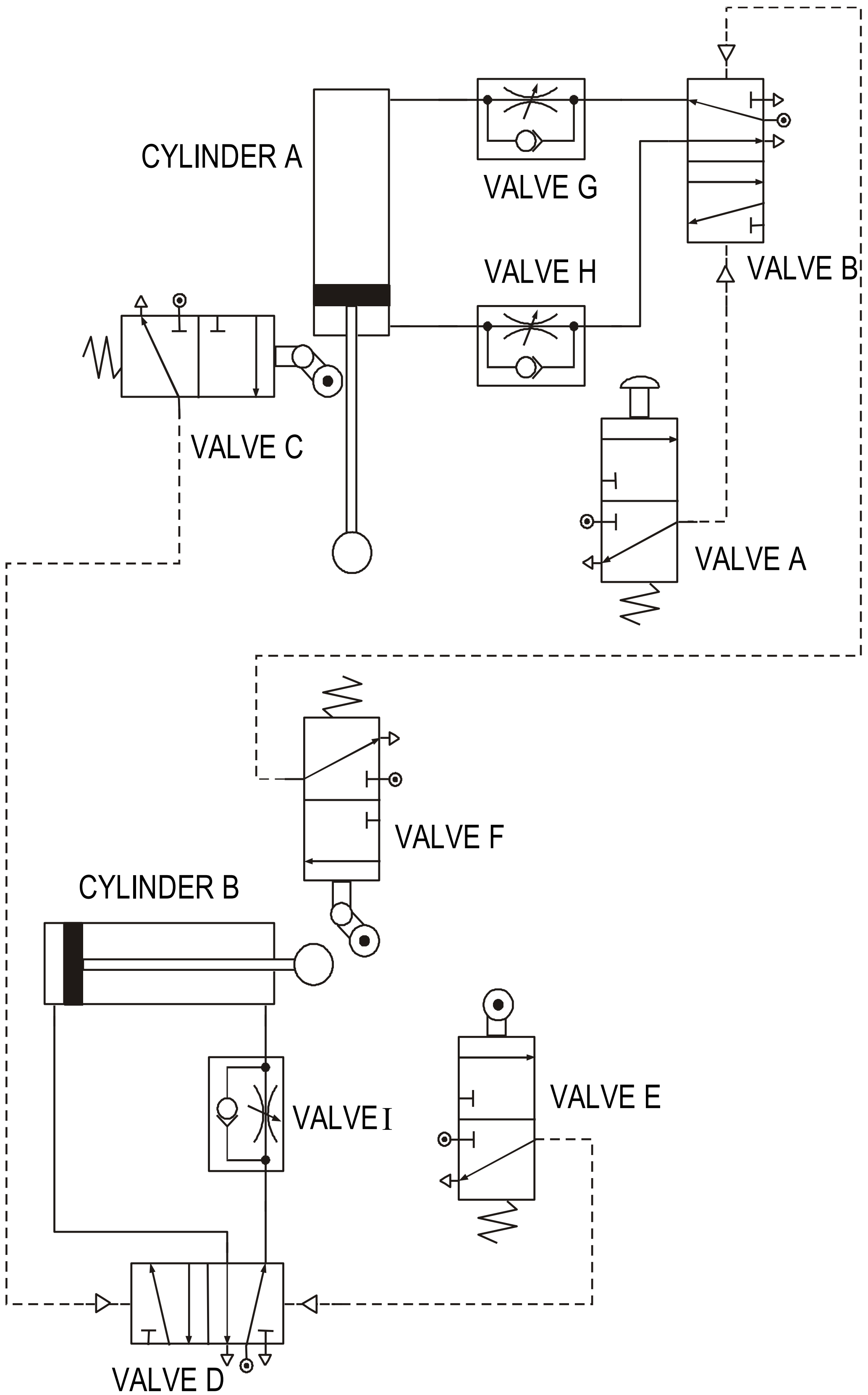
**Stage 1**
Cylinder A instrokes to raise the furnace door.

**Stage 2**
Cylinder B outstrokes and pushes the metal block into the furnace.

**Stage 3**
Cylinder B instrokes.

**Stage 4**
Cylinder A outstrokes and closes the furnace door.

The pneumatic circuit that carries out this operation is shown over the page.



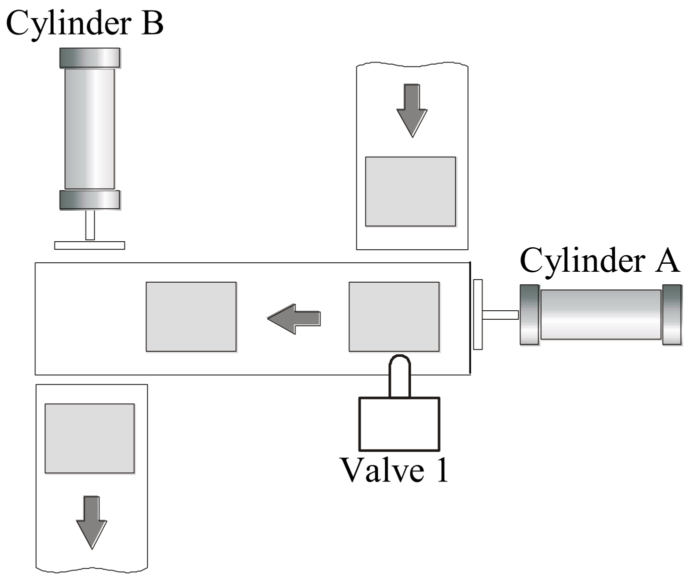

The system begins by actuating valve A. This changes the state of valve B and causes cylinder A to instroke, raising the door. When fully instroked, or *negative*, the piston trips valve C and this sends a signal to valve D. This 5/2 valve changes state and sends cylinder B *positive*. When fully outstroked, the piston trips valve E and the cylinder instrokes. When *negative*, valve F is actuated and causes cylinder A to outstroke and stay in the *positive* position. The system stops and waits for a signal from valve A.

We can summarise the sequence of this circuit as follows.
Start, A-, B+, B-, A+, Stop

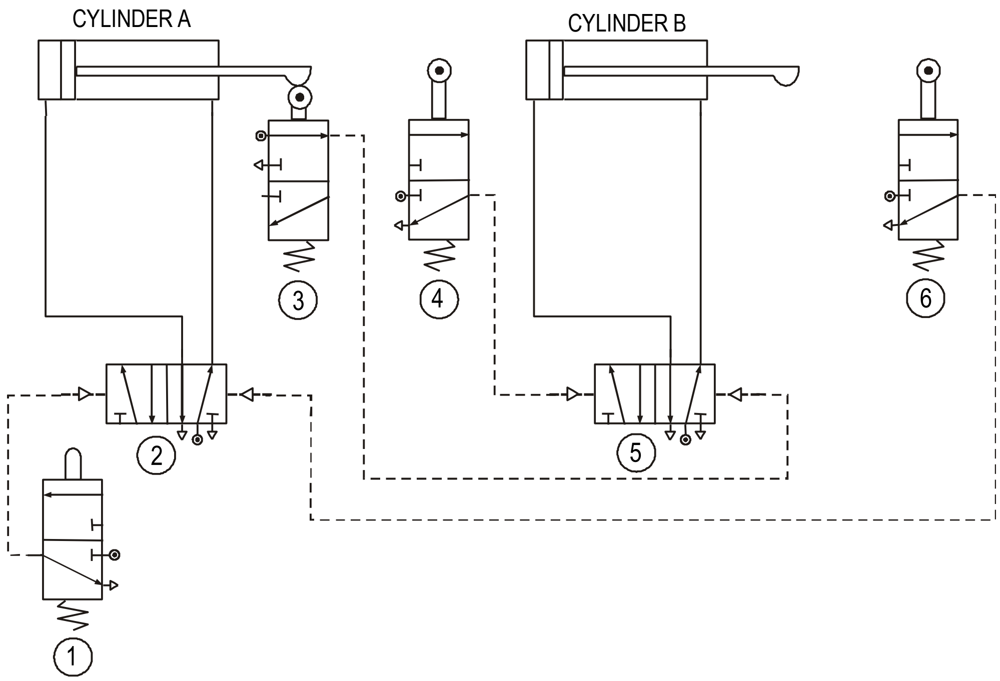
**Assignment 1**

1. Study the sequential circuit on the previous page.
   (a) Name the components labelled Valve D, Valve F and Valve H.
   (b) If Valve H were removed from the circuit, explain the effect this would have on the operation of the furnace door.
   (c) Using appropriate terminology, explain how the circuit operates, starting, from when Valve A is pressed.
   (d) A short delay is required before Cylinder B goes positive. Redraw the circuit to take this into account.

2. A pneumatic system is used to transfer packages between conveyor belts as shown. The pneumatic circuit is also shown.




The sequence of operation of the cylinders is A+, B+, A-, B-.



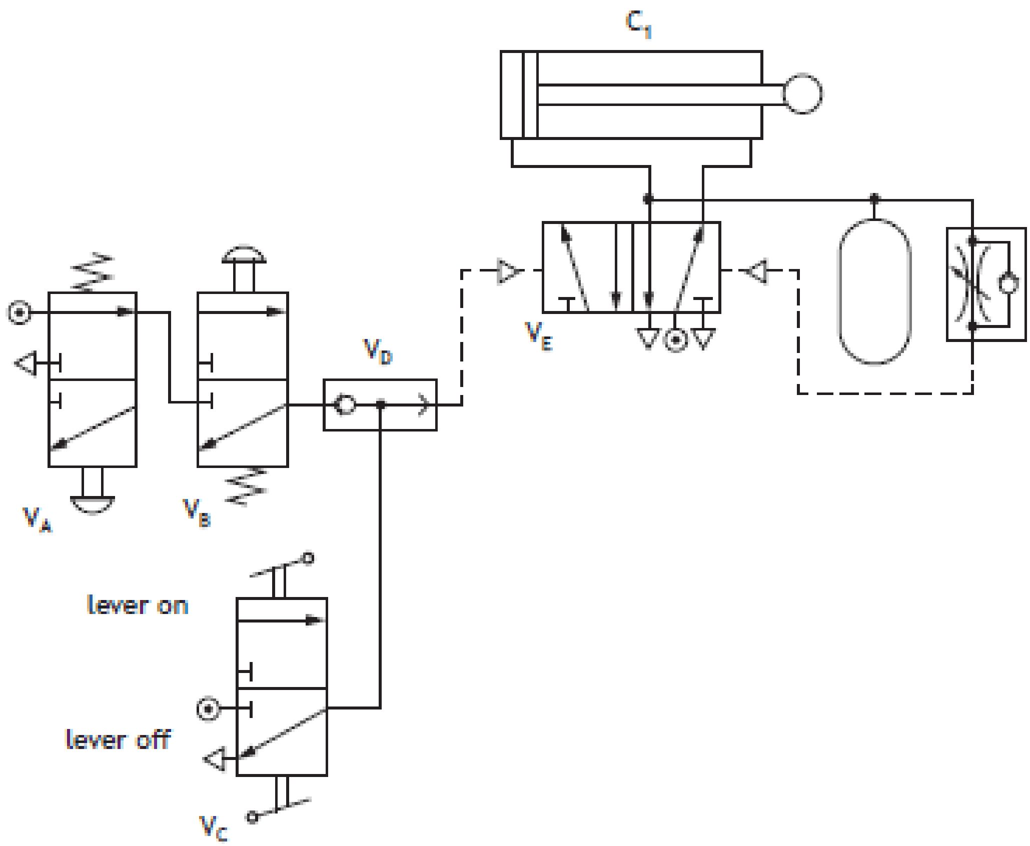

(a) Name valves 1, 2 and 4.
(b) Describe how the circuit operates.
(c) If the packages were too light to actuate valve 1, describe another way to detect the packages.
(d) The outstroke speed of the cylinders needs to be slowed down. Describe how you would do this.

2023 Past Paper

10. A mechanical engineer must design a pneumatic circuit to meet the following criteria:

- when push buttons on $V_A$ and $V_B$ are not pressed, or when the lever on $V_C$ is thrown to the on state, a double-acting cylinder must outstroke $\left(\text{Outstroke} = \overline{A}.\overline{B} + C\right)$
- a short time after the cylinder outstrokes, it must instroke automatically
- the cylinder must instroke slowly.

An initial design for the circuit, shown below, is known to have faults.



**10. (continued)**

(a) Describe four faults with the circuit design shown opposite. **4**

Fault 1 ____________________

____________________

____________________

Fault 2 ____________________

____________________

____________________

Fault 3 ____________________

____________________

____________________

Fault 4 ____________________

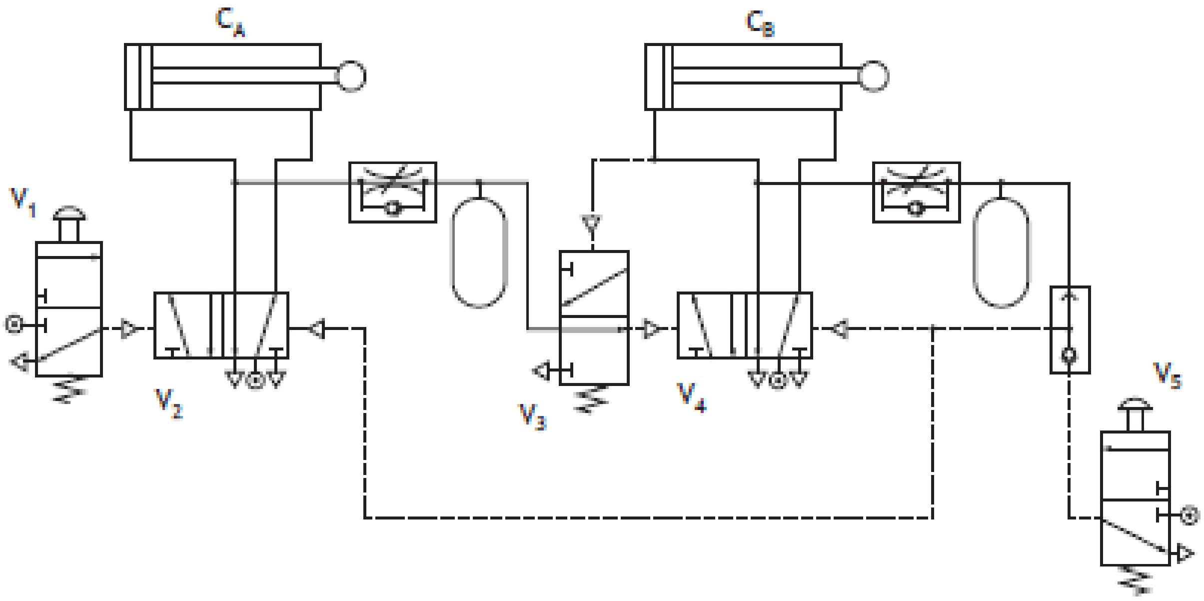
____________________

____________________

MARKS

**10. (continued)**

A further part of the system controls the motion of two cylinders.




(c) Describe, with reference to the components, the full operation of the pneumatic circuit when the button on $V_1$ is pressed. **5**

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

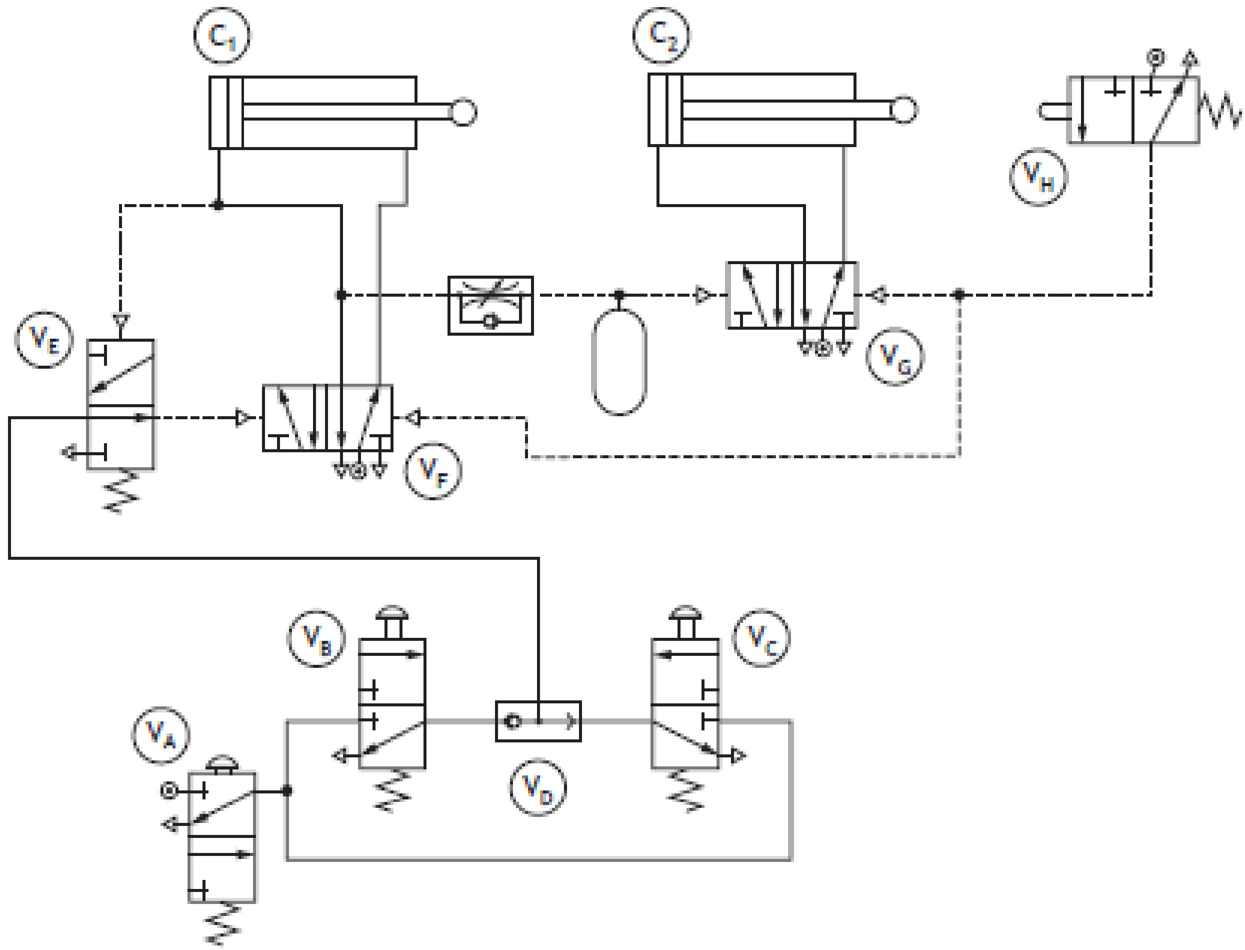
______________________________________________

______________________________________________

______________________________________________

**10. (continued)**

Two further cylinders are to be controlled by the following circuit.



**10. (continued)**

(c) (i) Describe the operation of this circuit, highlighting the function of each component and the conditions that will cause the cylinders to instroke and outstroke. **6**

When $V_A$ . . .

The engineering team are considering changing the circuit shown opposite to one that is operated by a microcontroller.

(ii) Describe two reasons why using a microcontroller-based system is preferred to a fully pneumatic system. **2**