RIMS
Research Instrumentation
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DEV-2758

Industrial Pneumatic Trainer

Operations Manual

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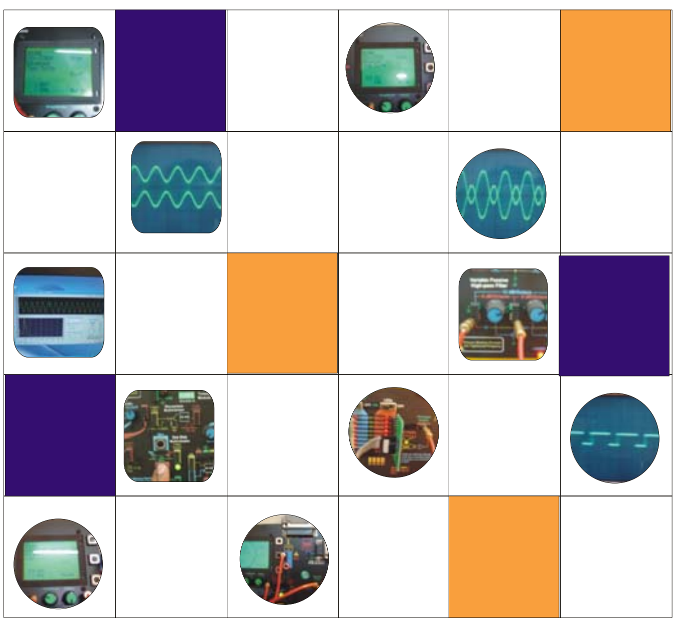

COMPREHENSIVE & ILLUSTRATED
EASY EXPERIMENTS STARTUP
LAB MANUAL

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Once you have made it through this guide, you will have a firm grip on your lab experiments and operations of the RIMS product you are using. How to get your training equipment operational, basic maintenance and setting up desired experiments will just be a breeze. Everything you need for a quick and easy start is presented here—useful hints and tips makes it simple to conduct your lab and hands-on training sessions. We are happy that you have joined our vast community of over 30 thousand valued users, which grow as we bring you the latest technology at most competitive prices. We value your business and hope that you will enjoy being an important member of the RIMS Education Community.

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PNEUMATIC SAFETY

Mechanical devices, especially fast acting, powered mechanical devices can be dangerous Pneumatic systems are powerful and fast acting. It is possible to avoid injuries by recognizing and identifying dangerous conditions. The first rule of pneumatic safety is: Always wear safety glasses when working with pneumatics. In this lesson, participants will learn to recognize particular hazards associated with the speed and forces generated by pneumatic systems. Participating students will also identify safe practices when working with and around pneumatic systems.

Objectives
Estimate and calculate velocities of moving objects.
Describe and demonstrate the potential for injury from pneumatic powered devices and systems with respect to the velocities and forces they generate.
Describe safe practices to follow when working with and around pneumatic components.

Terms	Materials
Force Pressure Velocity HRT Kilogram (kg) Pounds (lbs) Newton	Computer Calculator Dial Callipers Ruler Pens Internet Access Note Book SMC Pneumatics Training Disc Pneumatic Storage Reservoir Tubing On-Off Valve Pressure Regulator Solenoid Valve Pneumatic Cylinder 12Volt Battery Test Leads

Pneumatics Are Potentially Dangerous Because They Are Fast
Pressurized gases are capable of storing significant amounts of energy, and releasing this stored energy very quickly. Compressed air systems are capable of generating significant forces that power fast moving mechanisms. When things move fast and with great force, they become very dangerous. Pneumatically powered mechanisms can move at speeds that are too fast for humans to safely react to.

How Fast Is Too Fast?
When the speed of mechanisms exceed our reaction time they become dangerous. The time required for a person to "See" a stimulus, process the observation, send nerve impulses to the appropriate muscle groups, and effect an appropriate physical response is referred to as the Human Reaction Time (HRT).

The best way to appreciate the limits of human reaction times is to measure your response time: This can be accomplished using a 12" ruler and a simple algebraic equation. Down load the **Human Response Test** worksheet in the learning tools section of this lesson, and working with a partner, calculate your HRT's.

A good way to understand the velocity and force of pneumatic systems is to compare them to velocities and forces we are familiar with.

Velocity In Human Terms
The average velocity for the world's fastest sprinters is approximately 402 inches per second, or 33.5 feet per second over 100 meters. This is close to 23 mph! Darn fast, right?

Here is Another Example of Velocity in Human Terms
The current world record mile time is approximately 3:44.39 seconds. The average velocity of a world class runner is about 294 inches per second or 24.5 feet per second or 16.7 miles per hour. Certainly not as fast as 100 meter sprinter, but then, the distance is 16 times greater!

Velocity In Pneumatic Terms
Paintball guns are pneumatically powered devices. Paintballs regularly move at speeds that exceed 3000 inches per second, or 250 feet per second (fps, or 170 miles per hour.

Compare the velocity of a paintball (250 ft/sec) to the velocity of a world record sprinter (33.5 ft/sec.)

Conclusion: The paintball velocity is more than 7 times faster than the runner! Some Pneumatic actuators (Cylinders) are capable of operating at speeds up to 1000 inches per second. This is more than 83 feet per second, or nearly 60 miles per hour (mph).

At that speed an actuator rod can move (or cause something to move) more than 16' feet in the time it takes a person to react.

It is easy to see why pneumatic powered systems are potentially dangerous. They are capable of operating at speeds that exceed our ability to safely react.

Pneumatics Develop Significant Forces

Force in Human Terms
The world's top Olympic weight lifters, Pisarenko, Taranenko and Chemernkin are all capable of putting 550 lbs (249 kg) overhead. These are giant men, each weighing more than 300 lbs (136 kg).

Force in Pneumatic Terms
A 10 lb. (4.53 kg) Pneumatic cylinder with a 4 inch bore charged to only 145 psi (1mPa or 10 bars) can easily develop more than 1,800 lbs (8000 N Newton's) of force! More than 3 times that developed by the world's strongest men.

Pneumatic components can produce forces far in excess of the world's strongest human, and deliver these forces at speeds in excess of the world's fastest runners! This makes pneumatic powered systems particularly dangerous to people who are unwilling to take the time to develop the habits and understanding necessary to prevent accidents.

Safety Considerations
Pressurized air represents a source of considerable potential energy, and potential danger as well. Precautions must always be taken to prevent accidents from the use and misuse of compressed air. Improper selection or improper use or failure of the components described in this lesson can cause property damage and personal injury.

The pneumatic components used in the Educational Systems products are specifically selected to minimize the dangers associated with pneumatics. The force, speed, and size of these components are carefully scaled to classroom learning environments. This does not mean however, that accidents can't happen!

When Dealing With Pneumatic Components Keep These Habits In Mind.

1. Always wear safety glasses.

2. Read and obey all pneumatic safety rules

3. Compressed air should never be directed towards or applied to any part of the human body. Never direct a compressed air stream at your face or anyone else's.

4. Use the on/off /relieving valve supplied in the kit in every pneumatic circuit you design or build. This valve will depressurize downstream components.

5. Vent and depressurize all circuits and components when you are finished using them.

6. Never connect, or activate a pressurized system without direct supervision of a qualified person, and or express permission from a supervising instructor.

7. Never place yourself, another person or any part of a person in the line of action of a pneumatic actuator, or system component. This means that you never point moving parts toward anyone, ever. Treat pneumatic components like loaded guns.

8. When activating a pneumatic system, be certain that you have examined all the components and you have predicted what will happen when the system is energized.

9. Check and secure all of the mountings, fittings, piping, tubing, connectors and connections before connecting any pneumatic components or systems to a compressed air supply.

10. Disconnect battery leads and vent compressed air supplies BEFORE any adjustments, maintenance or dismantling of a pneumatic circuit is begun.

11. Allow only one person near the pneumatic system while it is being activated or deactivated.

12. Never heat the pressure storage tank.

13. Always use a regulator and pressure gauges in your system to monitor systems conditions.

14. Never over pressurize cylinders, storage tanks, directional valves or other system components. Never exceed the pressure rating of a pneumatic component; this is a recipe for disaster.

15. Use only the tubing valves, cylinders and regulators supplied.

16. Maximum allowable pressures of all products must be strictly observed. Most commonly available pneumatic components are designed to operate in the 100 psi range. Identify and remember the published design and pressure specifications of the pneumatic components supplied in the IDS kit. Never design or build a pneumatic circuit or cause the pressure within a pneumatic component, to exceed the specified design pressures!

Pneumatic System Components

Regulator

A device that adjusts and maintains a pre-determined pressure within a pneumatic circuit. The regulator maintains pressure in the downstream components as long as there is a pressure differential between the reservoir and the "Required" operating pressure. The reading on the regulator mounted gauge indicates the regulated or circuit pressure.

Speed Control Or Flow Control Valves

A device that controls the flow of pressurized air in a pneumatic circuit. Speed control valves are used to adjust the rate of airflow into or out of a pneumatic circuit or component. The rate of flow through a circuit or component affects the speed of the component. The higher the flow rate, the faster the component will operate. Note: Controlling air flow out of the cylinder is the preferred choice for accurate and smooth control of slower moving actuators.

Pneumatic Cylinders

Linear actuators that is available in thousands of different configurations. Cylinders refer to devices with pistons of various diameters and strokes of various lengths. They are most commonly specified as single acting (powered in one direction) or double acting (powered in both directions). Single acting spring return cylinders are more economical with respect to air consumption. The pneumatic cylinders supplied in the IDS Invention and Design System are single acting, spring return valves.

Solenoid Valves

Solenoid valves are electrically operated valves that control the direction and flow of pressurized air to and from pneumatic actuators. Solenoid valves can be either monostable, (they spring return to a preferred or default condition either on or off) or Biteable, (having no preferred or default condition thus remaining where it was last positioned either on or off) Pneumatic valves can be hand, (mechanical) electrically (solenoid) or air (pilot) operated. For the purpose of electronically controlled machines we will only consider solenoid controlled directional sliding valves. The kit includes a 3 port, 2 position electrically operated solenoid valve.

Never Exceed The Pressure Ratings Of Pneumatic Components

Pneumatic power system components control and transmit energy stored in pressurized gas. The IDS pneumatic components are rated for at least 100psi (100 pounds per square inch). This is a working pressure commonly associated with high performance bicycle tires.

Always Use A Regulator

Use a bicycle pump to fill the pneumatic reservoir. Do not pressurize the storage reservoir to more than 150psi, and never construct or use a pneumatic circuit without a regulator. This will greatly reduce the chances of over pressurizing the system. It is not necessary to generate storage tank pressures greater than 150 psi.

INTRODUCTION TO CONSTRUCTING PNEUMATIC CIRCUITS

This unit provides students and teachers with the information and skills they need to use the pneumatic components. Students who understand the fundamental principles involved in the operation of pneumatic components can safely design and build working pneumatic modules. Students can then integrate these modules into machines and mechanisms they design. Built machines and mechanisms can be used in engineering contests played at the classroom, school, district, state or national level. The information, activities and slide shows and worksheets provided in this unit can be presented in four to five 45 minute lessons.

Objectives

1. Describe the use and function of each component in the IDS pneumatic circuit.
2. Assemble a working pneumatic circuit
3. Perform basic pneumatic experiments.
4. Use pneumatic components safely.

Terms	Materials
1/8 inch NPT Thread 3 Way Shut Off Valve Bicycle Pump Bore Breadboard Check Valve One Touch Fittings Pneumatic Cylinder Pneumatic Reservoir Pneumatic Symbols Ports Pressure Regulator Schrader Valve SMC Computer Based Learning Module Solenoid Valve Stroke Sub Assembly Volume Work	150 psi Bicycle Pump 1 Pneumatic Reservoir 1 3 Way Shut Off Valve 1 Regulator 1 Solenoid Valve 1 Pneumatic Cylinder or Linear Actuator Tubing cutter or sharp razor knife 1 IDS kit

Introduction to Constructing Pneumatic Circuits

The purpose of this lesson is to provide students and teachers with the knowledge necessary to use the IDS pneumatic components correctly and safely. It is advisable to build and test the operation of pneumatic modules and sub assemblies before attempting to integrate the components into a working mechanism.
It is advisable that students and teachers become familiar with the feel, function and placement of the pneumatic components used in the basic IDS circuit. This is best accomplished by building working mechanisms and developing a database of pneumatic experience. Understanding and using pneumatics correctly, safely and creatively requires time and practice.

Note: Never build a pneumatic circuit WITHOUT A REGULATOR. The pneumatic solenoid and cylinder are rated for working pressures below that of the reservoir. Passing unregulated pressurized air from the reservoir directly to the solenoid or cylinder can damage the components and result in personal injury. ALWAYS WEAR SAFETY GLASSES WHEN WORKING WITH PNEUMATIC COMPONENTS

The Invention and Design System kit includes six pneumatic components. These components are:

The Bicycle Pump

The Pneumatic Reservoir

The 3 Way Shut Off Valve

The Regulator

The Solenoid Valve

The Pneumatic Cylinder or Linear Actuator

The quick disconnects

The Speed Controls

Pneumatic components are designed to accomplish one or more of the following tasks; store, condition, direct, control or utilize compressed air to perform useful work.

Work
Work is defined as the result of force acting through a distance.
WORK = FORCE x DISTANCE

Example: When the piston of a pneumatic cylinder exerts a force of 10lbs through a 1 inch stroke, the amount of work = 10 inch pounds.

It all Starts with a Pump and Ends With an Actuator

Work is performed by a pump to compress and store atmospheric air in the reservoir.

The pressurized air is routed from the reservoir to the 3 way shut off valve. This valve controls the flow of air to the circuit.

From the 3 way shut off valve the air is directed to the regulator which controls the pressure of the air in the circuit.

Pressure adjusted air is fed to the solenoid valve. This valve controls the direction and flow of air to the actuator.

The actuator extracts work from the compressed air by allowing it to expand within a confined space (cylinder) and against a moving surface (piston).

Note: Speed control valves affixed to the pneumatic cylinder (actuator) control the FLOW of air into or out of the cylinder. These valves DO NOT control AIR PRESSURE.

Once the work has been extracted, the air is exhausted back through the solenoid valve and into the atmosphere.

Note: Pneumatic circuits like the one used in the IDS kit are commonly open circuits. In an open circuit atmospheric air is pressurized, used in the pneumatic circuit and then exhausted back out into the atmosphere. This is one way that pneumatic circuits differ from hydraulic circuits. Hydraulic circuits are closed circuits. The same fluid is continually re-circulated within the circuit

Introduction to Pneumatic Components
The pneumatic components are described in the order in which they are connected in a working pneumatic circuit.

The Bicycle Pump

Hold this component in your hands as you read the following description.

Bicycle Pump Specifications

Pump Bore is approximately 1.180 inches or 30mm

Pump Stroke is approximately 17.3/4 inches or 450mm

Hose Bore is approximately 1/4 inch or 6mm

Hose Length is approximately 44 inches or 1117 mm

A bicycle pump is comprised of a cylinder, piston and piston rod. A handle is fixed to the Piston rod. When the handle is depressed, the piston travels the length of the cylinder, reducing the interior volume of the pump cylinder and increasing the interior air pressure. This increase in air pressure is proportional to the decrease in volume. The length of the piston travel is called the stroke, and the inside diameter of the cylinder is called the bore.
Conversely, as the pump handle is extended, the piston rises and the volume inside the pump cylinder increases.

The increase in volume causes the pressure inside the pump cylinder to drop below the surrounding (atmospheric) pressure. The result is that atmospheric air is drawn into the pump through a flapper valve built into the piston. When the pump handle comes to rest at full extension the interior pump volume is at maximum and the air pressure within the pump is at normal atmospheric pressure.

Boyles Law describes the relationship between pressure and volume in a closed system like the pump. Gas laws developed by physicists and chemists are covered in depth in other lessons
Charles Law describes the relationship between pressure, volume and temperature of a gas in closed system. If you pump the air into the reservoir with rapid pump strokes, the temperature of the pressurized air will increase. You will be able to feel this temperature increase if you hold the reservoir while a partner operates the pump.

The air capacity of the pump is described in terms of standard atmospheric pressure and volume.

Solving for Volume we get approximately 19 cubic inches at ambient air pressure and temperature.

As the pump handle is depressed, the interior volume of the pump cylinder decreases and the pressure and temperature of the air inside the pump increases. When the pump is connected to the reservoir, the compressed air inside the pump is forced through the pump hose, through the Schrader valve and into the reservoir. The Schrader valve is a one-way (check) valve that allows higher-pressure air to enter an area of relatively lower pressure. The Schrader valve used on the reservoir is the same valve used on bicycle tires and operates in exactly the same way.

Caution: ***The pneumatic circuit is powered by the energy of compressed air stored in the pneumatic reservoir. To prevent accidental overpressure, the reservoir should only be filled using a bicycle pump. In addition to adding an extra margin of safety, pressurizing a pneumatic circuit with a hand pump is a great way to appreciate and understand the amount of work (energy) necessary to store compressed air in the reservoir.***

Always use Safety glasses when working with pressurized pneumatic circuits

The Compressed Air Reservoir or Storage Tank

Hold this component in your hands as you read the following description.

Reservoir Specifications

Reservoir Bore is approximately 1-1/2 inches or 38mm

Interior Cylinder Length is approximately 5-1/4 inches or 133mm

Recommended Operating Pressure for the reservoir is 150 psi. Do not exceed this operating pressure or the regulator will be damaged

The bicycle pump transforms work into the (Potential) energy of pressurized air. This pressurized air is stored in the reservoir. The potential energy captured or stored in the reservoir comes from the energy (Work) you expended pumping the air into the cylinder. In other words, some of the work of pumping the air is now stored and ready for use within the reservoir.

The reservoir is comprised of a Stainless Steel tube with 2 aluminium end caps. The end caps are identical, and each has a 1/4 inch NPT, ***National Pipe Thread***, threaded port and threaded mounting bosses.

A Schrader valve is threaded into one end of the reservoir. The end of the bicycle pump hose locks onto the Schrader valve during filling. The locking feature allows a single person to fill the reservoir.

A One Touch, quick connect fitting is threaded into the other 1/8 inch NPT (National Pipe thread) port. These fittings provide an easy means of quickly assembling and disassembling pneumatic circuit components by allowing hoses and tubes to be easily and quickly disconnected and reconnected.

3 Way Shut Off Valve

Hold this component in your hands as you read the following description.

The 3 way shut off valve is referred to as a 3/2 manual valve.

The 3 way shut off valve is connected between the pneumatic reservoir and the regulator. This hand operated valve has 3 ports and 2 states or operating positions.

3 Ports

The **P** port is connected to the pressurized air supply or reservoir.

The **A** port is connected to the circuit and supplies the circuit with pressurized air when the valve is turned on.

The **E** or exhaust port vents the circuit when the vale is closed, and serves to depressurize or de-energize the circuit.

Off Position: In this position the valve handle is perpendicular to the flow of air through the valve. As the valve handle is turned to the off position the valve will vent the circuit pressure.

On Position: In this position the valve handle is parallel to the flow of air through the valve.

Venting the circuit during shut down is a pneumatic safety feature. Venting or depressurizing the pneumatic circuit and components prevents the possibility of inadvertent operation of the system or any system components.
Note: The 3 Way Valve is a directional valve. Be certain to align the flow of air through the valve with respect to the directional arrows embossed on the valve housing. Connecting the valve in reverse will vent the reservoir when the valve is turned on.

The Regulator

Hold this component in your hands as you read the following description.

Note: Maximum Regulator Operating Pressure is 145 psi or 1Mpa

The regulator controls the pressure within the pneumatic circuit. The pressure within the pneumatic circuit determines the force generated by the actuator. Higher air pressures requires more air to be forced into a given volume, therefore higher pressures affect the rate at which the stored pressurized gases are consumed.

As the pressure of a gas increases, the density or amount of gas per unit volume increases. The reservoir contains a finite amount of air at any given pressure. When the pneumatic circuit pressure is increased, stored air is consumed at a proportionally higher rate. The result is that increasing the pressure results in greater actuator force, but fewer actuator operations. The regulator allows the air pressure within the circuit to be adjusted to meet the performance requirements of the pneumatic system.

It is not always necessary for student engineers to operate the pneumatic systems at maximum pressure in order to ensure maximum performance. Well-engineered machines are optimized with respect to required force and air reserves. This is an engineering design challenge. Higher pressure means fewer cycles from the pneumatic cylinder.

One conclusion that might be drawn from this knowledge is: Do not set the regulator to maintain a pressure higher than what is necessary for the design function of a given mechanism. To do otherwise would result in an unnecessary depletion of stored air reserves.

Regulator Operation

The regulator controls and maintains the pneumatic circuit pressure. The regulator prevents both under pressure and overpressure situations. As pressurized air is consumed by the actuator, pressure on the downstream (circuit) side of the regulator drops. This drop in pressure creates an imbalance of forces acting between a tensioned spring and a pressurized diaphragm valve within the regulator. The imbalance causes the spring to open a valve connecting the circuit to the (higher pressure) air stored in the reservoir. As the higher pressure air flows from the reservoir, through the regulator and into the circuit, the circuit pressure increases. This increased pressure acts to re-establish the balance of forces between the spring and diaphragm within the regulator, and closes the valve connecting the reservoir to the circuit.

Study the text and animations found in section 3.0 section of the SMC Computer Based Learning Software for the best explanation of the regulators operation.

3/2 Solenoid Valve

Hold this component in your hands as you read the following description.

Solenoid Specifications

Voltage 12 volts

Power Consumption 1 Watt @ 42mA

Cv .008

This valve is a 3/2 (Read Three, Two) normally closed solenoid valve used to operate single acting pneumatic cylinders.

The designation, 3/2 refers to the number of ports (3) and the number of positions (2) or States of Operation of a pneumatic valve.

The first number (3) refers to the number of ports through which air can enter or leave the valve. Counting the ports or holes in the valve body is an easy way to determine the number of ports in a valve. The solenoid valve in the IDS kit has three holes, or ports. These ports are labelled as follows:

P1 This is the Pressure Port. This is the connection port from the solenoid valve to the regulator or pressure line.

A2 This is the actuator port. This is the connection port from the valve to the pneumatic cylinder or actuator.

E This is the exhaust port. This is where the spent air is exhausted from the pneumatic cylinder or actuator to atmosphere.

The second Number (2) refers to the number of possible operational states or modes. The solenoid valve used in the IDS kit has 2 modes:

OFF

This is the default mode in which the A2 actuator port is normally closed (NC) and the exhaust port is normally open. When the solenoid valve is not energized, it defaults to this mode or position. (NO).

ON

In this position solenoid is energized by an electrical current and a poppet valve within the solenoid body is opened. This closes the E (exhaust) port and opens the A2 (Actuator) port. The ON condition is maintained as long as the solenoid valve is energized. When power to the circuit is disrupted or shut off, the internal valve spring closes the A2 (Actuator) port and opens the E (Exhaust) port. This returns the valve to the default or NC state.

The solenoid valve is electrically actuated. When the valve is energized, a 12 volt 42mA (low amperage) current passes through a coil of wire within the valve. The electrical energy passing through the coil induces a magnetic field around the coil. This magnetic field draws an iron core into the center of the coil and actuates a poppet valve within the body of the solenoid valve. The poppet valve opens a path from the pressure port (P1) on the regulator side of the valve, to the actuator port (A2) on the pneumatic Cylinder or actuator side of the valve.

When the coil is not energized (The current to the coil is turned off), the poppet valve returns to a default position closing the connection between the pressure port (P1) and the actuator port (A2), and opening the connection between the actuator (A2) and the exhaust port (E). The pressurized air within the actuator passes back through the solenoid valve, and is exhausted into the atmosphere.

The solenoid valve can open or close a circuit pressurized to .8 MPa (116psi) within 3.5 ms. This is more than 10 times the stimulus response time of the average person.

There is little wonder why fast, effective industrial automation systems are the result of pneumatics coupled with microprocessors.

The Pneumatic Cylinder (Actuator)

Hold this component in your hands as you read the following description.

Bore 5/8" or 16mm

Stroke 1" or 25.4mm

Single Acting Spring Return

The pneumatic cylinder contains the same components as the bicycle pump. These components are:

Cylinder

Piston

Piston Rod

Single acting cylinders are powered by pressurized air in one direction only. They are returned to their default position by the force of an internal spring.

The pneumatic cylinder supplied in the IDS kit is referred to as a Single Acting Cylinder with a Spring Return. This means that the cylinder is pneumatically powered in only 1 direction (extended). Single acting cylinders are also manufactured as a Single Acting Cylinder with a Spring Extend.

Double acting cylinders are often used when it is necessary to pneumatically power a mechanical action through extension and retraction.
The pneumatic cylinder or actuator is a mechanical device that transforms the energy of pressurized air into useful work.

The pneumatic cylinder or actuator operates in a manner that is similar but opposite to the bicycle pump. The bicycle pump transform work done on the piston and piston rod, into the potential mechanical energy of compressed air, while the pneumatic cylinder accomplishes the reverse of this. The pneumatic actuator is used to extract the stored mechanical energy of compressed air in order to accomplish useful work.

Examine the bicycle pump and the pneumatic cylinder closely. Even though you cannot See inside these components, it is clear that they share strong similarities.

The pump is an efficient mechanism for compressing air and thereby transforming work into the stored potential energy of compressed air. Conversely the actuator uses the same components, piston, piston rod and cylinder to extract the stored (potential) energy of the compressed air to perform useful work.

Force Generated by a Pneumatic Cylinder or Actuator

The theoretical pushing or pulling force created by a pneumatic cylinder can be mathematically determined. The actual forces must be measured directly. There is often a wide discrepancy between theoretical force calculations and measured forces. Actual cylinder force is diminished due to interferences and frictional losses in the mechanical assemblies and pressure drops that occur on the circuit as the cylinder fills with pressurized air. Air has mass, and is slowed by frictional forces between air molecules and the interior surfaces and bends of the pneumatic circuit components.

The theoretical force generated by a pneumatic cylinder is the product of the piston area and the internal pressure of the cylinder.

Theoretical Piston Force = Piston Surface Area x Internal Pressure

The piston area is calculated using the cylinder bore, and the pressure is approximated from the regulator gage reading.

Pneumatic Cylinder Speed Control

The pneumatic cylinder assembly includes a speed controller installed in the cylinder port. The speed controller is a combination needle valve and check valve used to control the maximum speed of the piston in either one direction or the other. The speed controller allows free flow of air in one direction and restricts the flow of air in the opposite direction. Changing the size of the orifice through which the air moves restricts the airflow into or out of the cylinder. This restriction is accomplished using a needle valve and seat assembly. Refer to the speed controller animation found in the SMC computer based learning module. Go to 7.0 Accessories and click on 7.2 speed controllers.

One Touch Quick Connects

These handy fittings allow builders to quickly assemble and disassemble circuits and components. Connections are made by fully depressing the (orange) plastic spring loaded collar before inserting or removing the tubing. Caution, be certain to fully depress the fitting before attempting to remove or insert the tubing. Attempting to extract the tubing from a quick connect fitting without fully depressing the fitting collar will damage the connector.

To ensure an airtight fit, prepare the tubing by cutting the ends square. Use a curved jaw tubing cutter and check that the tubing ends are square and free of burrs or rough edges.

Speed Controllers

A speed controller is attached to the input/output port of the single acting pneumatic cylinder. The flow of air into and out of the pneumatic cylinder is controlled by a metering system inside the speed controller. The metering system is essentially a threaded needle valve used to change the cross section of the orifice through which the air flows into or out of the cylinder. The air is allowed to flow through the speed controller freely in one direction, while being metered in the opposite direction. Speed controllers that meter either input air or output air are available.

It is important to understand the distinction between speed control valves and regulators. Speed control valves control the FLOW or air while regulators control the PRESSURE of the air within the circuit.

Connecting the Components

One Touch Quick Connectors

One Touch Fittings allow rapid and repeated assembly and disassembly of pneumatic circuits.

When connecting tubing with one touch fittings, please use the procedure outlined below.

1. Cut the end of the tubing square. Use cable cutters or a razor knife.

2. Fully depress the outer barrel of the one touch fitting.

3. With the outer barrel held depressed, insert the tubing until it bottoms out inside the fitting. Release the barrel.

Build the Circuit

Refer to the slide show included with this lesson.

Connect the 5 components using the 4 MM tubing supplied with the IDS pneumatic kit. Connect the components in the order

Note: ***Always confirm the direction of airflow through the component BEFORE attaching the tubing.***

Pressurizing the system is as easy as filling a bicycle tire. Connect the bicycle pump hose to the Schrader valve on the reservoir. Lock the pump fitting to the Schrader valve and pressurize the tank with the pump.

ANALYZING THE PNEUMATIC RESERVOIR

This lesson is a exercise in using basic math skills and physical science concepts to indirectly determine the interior volume of the pneumatic reservoir. The energy storage capacity of the pneumatic reservoir is a function of both the volume and air pressure it contains. One method is to mathematically determine the interior volume through a process of deductive reasoning and the application of mathematical relationships and measured values. This lesson will guide the participant through the process required to mathematically determine the interior volume of the pneumatic reservoir.

Objectives

1. Use engineering skills to determine an unknown volume through indirect means.
2. Construct a mathematical model of the interior volume of the pneumatic reservoir.
3. Make linear measurements with a dial calliper to an accuracy of plus or minus .001".
4. Measure, draw and compute the volumes of regular and irregular shapes.
5. Measure, research and compute the weight and density of irregularly shaped metal objects.
6. Compare calculated results with measured results.

Terms	**Materials**
Volume Pressure Reservoir Mathematical Models Density Weight Educated Guess	Pneumatic Reservoir Accurate Weight Scale Dial Callipers Calculator 7/16â€ Wrench .5 litter graduated cylinder

Calculate the Interior Volume of the Reservoir

Hold the Pneumatic Reservoir in your hand and consider this.

A.)How is it possible to calculate the interior volume of a space that is inaccessible?

B.) What must be known in order to make an educated (and reasonably accurate) guess about the interior volume of this cylinder?

Can you mathematically determine the interior volume without any additional help? If you think you can, and then please do so. If you are unsure of how to proceed, then please, read on.

Most students possess the skills necessary to determine the interior volume of the reservoir but simply are not sure of how to apply these skills and knowledge. This is where practice and experience can help.

Follow These Easy Directions

Using the work sheet follow the easy steps to measure and record the outside dimensions of the reservoir.

Note Before you start removes the large mounting nuts from both threaded ends of the reservoir.

Step One Determine the Reservoir Dimensions

A.) Draw a detailed sketch of the reservoir in the space provided on the work sheet.

B.) Create a 2 view sketch of the cylinder showing the front view. While it is possible to create the drawing in CAD, we suggest that you use sketches. Sketching is an essential engineering skill, and it is often a faster way to record dimensional data. Sketches can be refined into CAD drawings at a later date. This is why it is important to record all your work in your engineering notebook.

Step Two Measure and Record the Dimensions on Your Sketch

Note: Be careful to keep your units consistent. Use inches, millimetres or centimetres, whichever you are most comfortable with, but keep all your units consistent. It is wise to locate and use a conversion calculator.

A.) The length of the stainless steel cylinder body.

B.) The diameter of the stainless steel cylinder body.

C.) The length of the aluminium cylinder end caps.

D.) The diameter of the aluminium cylinder end caps.

E.) The length of the threaded mounting boss.

F.) The diameter of the threaded mounting boss.

Note: Disregard the tubing fittings. For the purpose of this exercise we will assume that the missing material from the flat sections of the aluminum end caps represents a mass approximately equivalent to the mass of the Schrader fill valve, and the tubing connector.

Step Three Weigh the Pneumatic Reservoir

Be certain that the reservoir is completely depressurized. Weigh the reservoir on a very accurate scale. Record your measurement in the Reservoir Analysis Worksheet found in the learning tools section of this lesson.

Note: Be careful to keep your units consistent. Use, grams, ounces, kilograms or pounds, whichever you are most comfortable with, but keep all your units consistent. It is wise to locate and use a conversion calculator.

Step Four Calculate the Volume of the Reservoir Components

Calculate the volume of the reservoir components listed in the illustration; Record these volumes on the Reservoir Analysis Worksheet. The pneumatic reservoir is comprised of 3 distinct shapes. Find the volume of each of these shapes.

1. The Aluminium End Caps (2 pieces)

2. The Threaded Boss (2 Pieces)

3. The Stainless Steel Cylinder.

Calculate the volume of the stainless steel cylinder using the outside dimensions (Length and Diameter). Measure the length of the Stainless steel cylinder between the aluminium end caps. The Stainless Steel cylinder is actually a tube, we will develop a mathematical strategy to determine the interior volume later in this lesson.

Note: For best results, use a dial calliper to obtain the measurements.

Step Five Research the Weight Density of Aluminium and Stainless Steel

Research the weight density of aluminium and steel and record this information on the Reservoir Analysis Worksheet. You can find the weight density of common materials in physics and chemistry text books, or on line. Use keywords like (Density of Common Metals).

Note: The weight densities of common metals are easily found on the web. Use a value for the density of steel in the event you cannot find a published value for stainless steel.

There are many alloys of steel and in turn, many alloys of stainless steel. Different alloys have different properties with respect to hardness, mach inability, strength, strength, weight, malleability and many other material characteristics.

Since you do not know the alloy from which the cylinder is made, use an average value. Remember, this is an exercise in approximation.

Step Six Use the Density Values to Calculate the Weights of the Components.

Note Remember to use consistent units. If the published weight density is given in lbs. per cubic ft., then be certain to calculate the volumes for the pneumatic reservoir components in cubic ft., or recalculate the weight density in cubic inches. Do not mix SI, Metric, MKS or Imperial units indiscriminately.

An algebraic expression that can be used to calculate the weight of a known volume of material looks like this.

Density of material (lbs/cubic ft) x Volume of Object (cubic ft) = Weight of Object

1.) Calculate the weight of the Aluminium end caps using the volume values you calculated in step four, and multiplying them by the weight density value for aluminium. Record this answer on the Reservoir Analysis Worksheet. Donâ€™t worry if everyone has different answers! Thatâ€™s pretty common.

2.) Add the calculated weight of both aluminium end caps and subtract that from the actual weight of the reservoir as determined in step three.

3. The difference in weight represents the approximate weight of the stainless steel cylinder. Record this answer on the Reservoir Analysis Worksheet.

Step Seven Calculate the Interior Volume of the Stainless Steel Tube using the Known Weight and Density of Stainless Steel.
In order to approximate the interior volume of the SS Tube, you have to think about what you know, what you donâ€™t know and then form a question whose answer will help you calculate the interior volume of the stainless steel tube.

Things You Know

a. The overall length and diameter of the stainless steel cylindrical portion of the reservoir.

b. The stainless steel section of the reservoir is tube shaped.

c. The weight density of stainless steel.

d. The weight of the stainless steel tube section.

Things You Donâ€™t Know

You have no way of directly measuring the wall thickness of the SS tube. This is a critical dimension necessary to calculate the interior volume of the reservoir.

In order to obtain the critical dimension you need to solve for the interior volume of the cylinder, you have to ask the right question, and answer it using the information you already posses.

The Essential Question

What would the wall thickness of the stainless steel cylinder have to be to equal the known weight value of the stainless steel tube?

Well there are several ways you could go about answering this question, and they are all legitimate. Here are three methods you might use. Try them all!

Method One, Guess and Try

Guess and try is a legitimate method of arriving at a working value. It is an iterative process of guessing and comparing your answer to a known value. It can be an effective way to find an answer, and it has the added value of building estimation skills and experience. Here is how it works

1. You know the exterior diameter and weight of the stainless steel cylindrical section, and you know that it is tubular. (Hollow inside.)From the work above you have the computed weights of the aluminium end caps and threaded bosses listed on your work sheet.

2. Make a guess about what you think the wall thickness might be.

3. Use that estimate to calculate the volume of the tube.

4. Use the volume and the weight density of SS steel to calculate the weight of the tube based on your wall thickness guess. Add this to the computed weight of the aluminium end caps found on your work sheet. You now have a guestimate of the weight of the complete reservoir assembly.

5. Compare your guesstimated weight to the actual weight of the reservoir. If the actual reservoir weighs less than your guestimate, then you will need to revise the wall thickness guess by making it thicker, conversely if your guesstimate weight for the reservoir is greater then the actual weight then you will need to revise your guesstimate by making the wall thickness less.

6. Adjust your wall thickness guess accordingly and guess again. Repeat this process until your guess results in a answer that is within 95% of the measured weight of the reservoir.

As you will find out, this is a workable method of determining the wall thickness, and therefore the interior volume of the reservoir. However it might take you many iterations (guesses, calculations and trys) to arrive at a reasonably accurate wall thickness value.

Calculating the Volume of a Tube is a Necessary Step for Determining the Interior Volume of the Reservoir

How to Calculate the Volume of a Tube

A tube is made up of two cylinders, an outside cylinder and an inside cylinder. The outside cylinder is formed by the overall length and diameter of the tube. The inside cylinder is smaller and it is formed by the hollow section inside the tube. This hollow inside section has a diameter equal to the outside cylinder diameter minus two times the wall thickness. In this case, the inside cylinder has the same length as the outside cylinder.

A Tube is comprised of two cylinders. The outside diameter and length of the tube describes one cylinder and the inside diameter and length describes the other cylinder. The difference in diameters equals 2x the wall thickness

Tube Volume = Volume of Cylinder #1 - Volume of Cylinder #2

Method Two, Mathematical Analysis

In order to mathematically determine the interior volume of the pneumatic reservoir we will perform several steps.

1.) Calculate the volume of the stainless steel cylinder based on outside dimensions (diameter and length) only.

V1 (Volume outside cylinder) = 3.142 (pi) x Radius^2 x Length

2.) Using the volume of the cylinder (assume it's a solid stainless steel cylinder) calculate the weight of the solid cylinder using the density formula.

Weight (Solid Stainless Steel Cylinder) = Density (Stainless Steel) x Volume (From preceding calculation)

Note: The approximate density of stainless steel is a 8gram per cc or 0.289016 lb/cubic inch.

3.) Use deductive reasoning to determine the weight of the stainless steel pneumatic tube.

We have already calculated the weight of the end caps and threaded bosses.

We know what the whole pneumatic reservoir weighs

We determined the weight of a solid stainless steel cylinder with the outside dimensions of the reservoir tube.

4.) If subtract the weight of the 2 end caps and threaded bosses from the weight of the whole pneumatic reservoir, we will have the weight of the stainless steel reservoir tube.

5.) We can subtract the weight of the stainless steel reservoir tube, from the weight of the solid stainless steel cylinder (step 2) and determine the weight of an imaginary stainless steel cylinder whose volume would be equal to that of the interior volume of the stainless steel reservoir tube.

6.) We can now solve for the volume of the interior cylinder using the density formula. If we know it's volume it is an easy step to determine the cylinders diameter since we already know the cylinder length. Her is how we can do this.

Density = Weight / Volume.

When we apply this formula to the volume of the interior cylinder we get,

$D = W / V$

Where

D = Density of stainless steel (approximately 8gram per cc or 0.289016 lbm/cubic inch)

W = Weight of the inside cylinder

V = Volume of the inside Cylinder

Note: We will use 3.142 as the value for Pi.

We can substitute the volume formula for the V value in the weight density formula above and this yields an algebraic statement that looks like this.

Density = Weight/ Pi x R^2 x length

Since the only value we do not know is the radius we can rewrite the equation in terms of the radius.

R = The Square root of (W/D*L*Pi)

7.) We now have the radius of the interior of the stainless steel tube, as well as the volume. How can we know we are correct? We can check the accuracy of our answer by finding the volume of the tube and using that value in the density formula to calculate the weight of the stainless steel reservoir tube. If this derived answer closely approximates the value we calculated in step 3, we can assume that we have a reasonable value for the interior volume of the pneumatic reservoir.

In order to calculate the weight of the tube we will need to know the inside and outside tube diameters as well as the wall thickness. We must assume the tube to be open at both ends since we are only interested in comparing the weights stainless steel and the end caps are made of aluminium.

Finding the wall thickness is simply a matter of subtracting the inside diameter from the outside diameter.

Think of taking a piece of typing paper (a rectangle) and rolling it into a tube. It can be imagined that the volume of stainless steel necessary to make a tube is equal to a rectangle whose dimensions are as follows,

Length = length of the tube

Width = centreline circumference of the tube

Thickness = wall thickness

Using these dimensions as well as the density formula we can mathematically solve for the weight of the stainless steel reservoir tube. A formula that will work might look like this,

Weight (of tube) = Density x Volume

Substituting the rectangular measures we get.

Weight (of tube) = Density x (Length x Width x Thickness) from the values listed above.

If this computed weight value closely matches the weight value we arrived at by subtracting the computed weights of the aluminium end caps from the actual weight of the entire reservoir, then we might assume we have a close approximation of the interior volume of the pneumatic reservoir.

Method Three, Indirect Measurement

It is possible to measure the interior volume of the reservoir before you read any further can you figure out how?

Follow these steps:

1. Unscrew and remove the Schrader valve

2. Unscrew and remove the one touch tubing connector.

3. Holding the reservoir level, slowly fill it with water.

4. When the reservoir is full, empty the reservoir into a graduated cylinder.

5. Read the volume of water in the graduated cylinder.

Compare this answer to the answer you obtained using the previously described method of determining the reservoir volume. Are your answers close?

Can you think of any other way to calculate the interior volume of the pneumatic reservoir without cutting it in half?

COMPRESSED AIR HISTORY

Good engineers build safe reliable machines that work predictably. The most effective design tools are knowledge and experience. An accurate understanding of how the physical world works coupled with the ability to mathematically model and predict results, defines good design engineering. This ability to mathematically model and predict the behaviour of mechanical systems is possible in great part because of the combined work of hundreds of scientists over several centuries. Taking the time to understand the chronology of events leading up to the technical sophistication we now enjoy, is a worthwhile endeavour. It is also a great way to acquire the knowledge and concepts that will help us design robust effective machines.

Objectives
The information and exercises contained in this lesson are intended to provide a historical perspective with respect to the science of pneumatics.
Describe how the relationship between temperature, volume and pressure in a gas was developed over time.

Terms	Materials
Archimedes of Syracuse Galileo Galilei Robert Boyle Evangelista Torricelli Jacques Charles Amadeo Avagadro Daniel Bernoulli Blaise Pascal Gay Lussac	School Library Public Library Internet Access

The Science of Pressure

An investigation that was resolved over centuries.

Archimedes of Syracuse Approximately 287-212 BCE

Archimedes was a creative engineer, physicist and mathematician whose seminal contributions to the sciences provided points of entry for the development of Geometry, Calculus, Physics and engineering. Archimedes experiments with buoyancy and density contributed to our understanding of the basic properties of matter.

Galileo Galilei 1564-1642

Remembered as an astronomer and the scientist who developed fundamental concepts about falling bodies. He was in fact a physicist and an ardent practitioner of the Scientific Method. In one experiment Galileo demonstrated that air had weight (and thus, mass). Gallileo also built devices that demonstrated the the change in density relative to the change in temperature of a fluid. Through the process of inquiry and experimentation, Gallileo opened the door for the slow development of the kinetic theory of gases.

Evangelista Torricelli 1608-1647

A student of Galileo, who is remembered for developing the Mercury Barometer. More important, Torricelli reasoned from his experiments that we are "Surrounded by an ocean of air"(The earth's atmosphere) and that this ocean of air can impart a force (weight).

Blaise Pascal 1623-1662

Blaise Pascal died young, but in one brief period of scientific creativity he authored a book on Geometry, invented a calculating machine that was a precursor to the computer, laid the foundation for probability theory and laid the conceptual framework for the independent discoveries of Archimedes (buoyancy) Galileo (weight of air) and Torricelli the weight of the ocean of air in which we live His observations led to the conclusion:

Pressure in a confined fluid (and gas) is transmitted equally and undiminished in all directions.

In a single statement he defined a new term, pressure, and he expressed it as a simple mathematical relationship.

Pressure (P) = Force (F) per unit Area (A)

P = F/A

Conversely

F = PxA

Understanding this simple algebraic expression will allow us to mathematically model and predict the performance of the pneumatic systems we design. This simple algebraic expression explains how it is possible to dramatically multiply forces within cylinders and transmit them significant distances through tubes and circuits within a pneumatic system.

Robert Boyle 1627-1691

While he is popularly regarded as the father of modern chemistry, Boyle made many significant contributions to the field of physics. Not least of which is a physical law that bears his name. Boyle realized that the product of the pressure and the volume within a closed system was constant (PV=k). He also noted that within a closed system, the pressure of a gas varies inversely with respect to volume. Increase the volume, and the pressure drops. Conversely if the volume is decreased, the pressure rises.

The algebra could not be simpler. A more useful expression comparing the effects of pressure and volume on a fixed amount of gas would look like this.

What Robert Boyle gave us was more than just an observation. He gave us the one of the essential tools of pneumatic engineering. Boyle provided us with a tool that could be used to mathematically predict the behaviour of a system.

Let's look at the implication of what Pascal observed and what Boyle quantified.

Pascal noted that pressure was force acting equally throughout a fluid or a gas. Boyle explained that if we reduce the volume of a given amount of gas by 1/2 then we double the pressure. The pressure is then doubled and acts equally on all surfaces of the contained gas!

The development of a universal gas law was nearing completion.

Jacques Charles 1746-1823

Jacques Charles enjoyed experimenting, and he was a daring inventor. In 1783 he heard news that the Montgolfier brothers had flown in a gas balloon. It is not certain that he knew they had used hot air to create the necessary bouyancy.He began to ponder how they may have accomplished this feat. He reasond they had filled the necessary volume with hydrogen, a recently discovered gas that was more than 10 times lighter than air. After several experiments Jaques Charles accomplished his solo flight in a hydrogen filled balloon!

Jacques Charles provided some key components necessary to formulate the ideal gas law.

He performed experiments that that allowed him to conclude that Pressure was proportional to temperature.

Pressure = Temperature x K (An constant) The algebra looks like this: **P = Tk**

Jacques Charles quantitatively measured the relationship between Temperature and pressure in a fixed amount of gas, and found the two quantities to have a proportional relationship. That is to say that a graph of changes in temperature with changes in volume forms a straight line.

The algebraic statement that expresses the relationship between Volume and Temperature in gasses with fixed pressures looks like this:

Jacques however used a Celsius scale. In this case the proportionality was not a direct proportion. The line of a graph plotting the change in Celsius temperature plotted against a change in volume did not pass through the origin of is temperature and pressure graph (0 degrees Celsius/0 cm3). It was not until Lord Kelvin discovered that if he added 273 to every degree Celsius, which the proportionality of volume and temperature in a fixed amount of gas became a direct proportion! The concept of absolute temperature was another step towards defining the ideal gas law.

If temperature affected the volume or pressure of a gas, the implication was clear. Gases, at their fundamental molecular levels, are mechanical in nature, and the laws of kinematics could help predict the behaviour of gases.

This algebraic tool allows us to predict the effects of changes in temperature, volume and pressure within a closed pneumatic system.

While temperature is certainly a factor in controlling pressure, this fact will not be considered in the problems that follow. Students are not expected to have temperature controls on their pneumatic systems. Never attempt to increase pressure by heating pressurized gas reservoirs.

Amadeo Avagadro 1776-1856

Amedeo Avogadro was, like many great scientists of his era, both a physicist and a chemist. He is credited with having coined the word molecule, and establishing the formula for water, H2O. Avagadros contribution to pneumatics lies in his most remembered work, the establishment of a law that bears his name, as well as a fundamentally important concept, Avagadros number.

Avogadro\'s law states that equal volumes of different gases at the same temperature and pressure contain equal number of molecules!

Avogadros Number 6.02 * 1023 This number refers to the number of molecules of a gas at standard temperature and pressure.

The volume occupied by one mole of any gas at Standard Temperature and Pressure is called its molar volume. This volume is the same for all gases. This volume is equal to 22.4 liters (a little more than 3/4 of a cubic foot).

The gram weight of the molar volume of any gas molecule can be found by adding the atomic weights of the atoms that combine to make the gas molecule.

A molar volume is always 22.4 liters. With this information we can compute the grams per liter of any gas as well as the weight of any quantity of any gas whose molecular formula is known.

Avagadros research contributed to the development of the Ideal Gas Equation. The Ideal Gas Equation describes the relationship between pressure, temperature and volume, and provides engineers with the tools they need to mathematically predict the behavior of gases under a variety of conditions.

Emil Clapeyron 1799-1864

Emil Claperyon is credited with having formulated the ideal gas law in 1834. Take a minute to look at the algebra that describes the relationship between Pressure, Volume, Temperature and the quantity of gas in a system. This simple statement represents the culmination of the work of dozens of scientists over hundreds of years and it includes the discoveries of the scientists recognized in this lesson.

The Ideal Gas Equation

$PV = nRT$
Where:

P = pressure in atmospheres

V = volume in litters

n = moles

R = Ideal gas constant = 0.0821 litter* atmospheres/mole* Kelvin

T = Temperature in degrees Kelvin

It is beyond the intended scope of this lesson to include a working explanation of the Ideal Gas Law. However it is important to know that this law demonstrates deep insight into the workings of gas systems. The understanding exhibited by this simple equation is used by men and women who design and manufacture safe reliable pneumatic systems. The fundamental laws that govern gas behaviour were discovered sequentially by men and women who made incremental contributions to development of our understanding of the behaviour of gasses. Each in turn, contributed to this growing body of knowledge. This is a story of pneumatic science, and it is representative of the story of science in general.

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