Part of Our Lives

We are all aware that gas is widely used as a fuel in our homes and in industry. We may not be aware that the gas we use comes from sources hundreds of kilometres away and is transported by Bord Gáis Networks to our homes and businesses through a network of pipelines. This network is an effective and efficient method of moving gas from source to user. However, the engineers who design and manage the network could not do so without a sound knowledge of the famous Gas Laws. In this lesson, we will look at these laws and see how they affect the operation of the Bord Gáis network as it carries gas from Scotland to users in all parts of Ireland.

Overview of the Network

The gas network is efficient because the gas can be compressed and transported at high pressure and this is more economical than liquefying the gas and transporting it by tanker. The network consists of high pressure underground steel pipelines that bring gas to cities and towns throughout the country and low pressure polyethylene pipelines within urban centres.

Onshore terminals at Gormanston, Co. Meath and Loughshinny, Co. Dublin receive the gas from Scotland through two undersea pipelines called Interconnector 1 and Interconnector 2. The gas pressure in these pipelines is about 150 bar (15 MPa). This is reduced to 85 bar before the gas is introduced into the Bord Gáis network. This high pressure gas moves through the main network until it reaches the local networks, where the pressure is reduced to 4 bar (400 kPa). Pressure units are explained in the panel below.

How Does the Pressure Vary?

The reduction in the pressure of the gas supplied to consumers is achieved at Pressure Reduction Stations (PRS) which regulate the pressure and flow of gas to the customer. This is a complex operation which is carried out continuously by a system of regulator valves that sense the downstream pressure (i.e. after the regulator). These valves automatically adjust the regulator orifice and so control the amount of gas passing through.

The Gas Laws

The Gas Laws describe how the volume ($V$), temperature ($T$) and pressure ($P$) of a mass of gas are related. They are based on important discoveries that were made in the 17th and 18th centuries. In 1662, Robert Boyle published his finding that the volume of a mass of gas was inversely proportional to the pressure; if the pressure was doubled the volume was halved. This relationship, which is known as Boyle’s Law, can be written as $P_1V_1 = P_2V_2$; this only holds if the temperature remains constant.

About a hundred years later, Jacques Charles found that the volume of a mass of gas increased when it was heated. Today this relationship is known as Charles’ Law: $V_1/T_1 = V_2/T_2$, as long as the volume is constant. These three relationships can be combined as follows: $P_1V_1/T_1 = P_2V_2/T_2$ for a given mass of gas. This is called the combined gas law and it essentially states that $PV/T$ is a constant (i.e. $PV/T = k$).

In 1811, Amedeo Avogadro stated that equal volumes of gas, at the same temperature and pressure, contain the same number of molecules. This is known as Avogadro’s Law. When this is put together with the combined gas law, we get the ideal gas law which states that $PV = nRT$, where $n$ is the number of moles of gas and $R$ is the gas constant. The ideal gas law can be applied to real gases because most real gases, at standard temperature and pressure, behave like an ideal gas.

A Complication

When the gas expands through the valve and experiences a pressure drop, it cools rapidly. This is called the Joule-Thompson Effect. For natural gas (methane, $CH_4$) the temperature drops by 0.6°C for every 1 bar drop in pressure. So, for a pressure drop of 66 Bar (for example, from 70 Bar at the valve inlet to 4 Bar at the outlet) the temperature drop would be 0.6°C × 66 bar = 39.6°C. The gas temperature at the inlet is about the same as the ambient temperature, which is about 5°C on average. So the downstream gas temperature will be 5°C - 39.6°C = -34.6°C. The valve and its associated control equipment could not operate at such low temperatures. If the valve stopped working, it would not
be able to control the downstream pressure, which might increase above its design limit and become a hazard. The solution to this problem is to heat the gas before it goes through the regulator in order to compensate for the temperature drop. This is done using heat exchangers. A heat exchanger is a device that passes heat from a hot fluid (in this case, hot water) to a cooler fluid (the gas) across the wall of a tube which separates them. The hot water is produced by boilers located at the PRS.

**Measuring the Customer’s Gas**

After passing through the regulators, the gas pressure is lowered to its required operating pressure and passes to customers through gas meters. These meters record the volume of gas and this information is used to calculate the customer bills.

**Monitoring the Network**

The Bord Gáis network operates day and night, transporting the gas from the onshore terminals to the customer supply points where it is required. Of course, the engineers need to know that the network is operating properly at all times. The network is monitored from a central control location in Cork using a state of the art Supervisory Control and Data Acquisition (SCADA) system.

If an emergency arises, any portion of the line can be isolated remotely by closing Block Valves (BVs). These are located approximately every 15 km to 20 km along the network. If a pipe breaks, the BVs on either side are shut immediately to minimise the gas escape and allow repairs to be carried out.

Bord Gáis

Bord Gáis was established in 1976 following the discovery of natural gas off the south coast of Ireland. It is majority owned by the Government of Ireland. It is now a leading energy supplier of gas and electricity to some 750,000 industrial, commercial and residential customers on the island of Ireland. The company was traditionally a gas company but is now expanding into other related areas such as electricity and renewable energy.

Bord Gáis operates two main businesses. Bord Gáis Networks constructs and extends the natural gas network and connects all customers and has developed one of Europe’s most modern energy networks. The retail arm of the business, Bord Gáis Energy, sells gas and electricity to customers.

In order to secure its future energy requirements in the most cost-effective and environmentally-sensitive way, Bord Gáis is constructing a highly-efficient electricity power station at Whitegate in Co Cork. It is also developing a number of wind farms and is supporting ongoing research in newer technologies such as wave, tidal, fuel cells, micro CHP and biogas. The company’s goals in renewable energy reflect and support the Government target of 30% energy produced from renewables by 2020.

Bord Gáis places great emphasis on education and actively encourages and supports students to understand energy, its use and the benefits of utilising energy efficiently. It also nurtures interest in researching and exploring other sources of energy.

Bord Gáis currently employs over 900 staff, 38% of whom work in engineering and technical roles.

You can find this, and other Bord Gáis lessons, on [www.sta.ie](http://www.sta.ie)

You can find out more about the work of Bord Gáis on [www.bordgais.ie](http://www.bordgais.ie).
Bord Gáis
The Gas Laws in Action
Teaching Notes

Syllabus References

The appropriate syllabus references are:

**Leaving Certificate Physics (pp. 26, 28)**
Pressure in liquids and gases.
Density and pressure: Definitions and units.
Demonstration of atmospheric pressure.
Boyle’s law.
Thermometric properties: Pressure of a gas at constant volume; volume of a gas at constant pressure.

**Leaving Certificate Chemistry (p. 45)**
States of matter.
3.2 Gas Laws: Boyle’s law; Charles’s law. Combined gas law.
The kinetic theory of gases (non-mathematical treatment): ideal gases; assumptions of kinetic theory.
Equation of state for an ideal gas: \( PV = nRT \) (units: Pa, m\(^3\), K).
Reasons why gases deviate from ideal gas behaviour.

**Leaving Certificate Technology (p. 28)**
Applied Control Systems.

Learning Outcomes

On completion of this lesson, students should be able to:

- Understand what is meant by the Gas Laws
- State Boyle’s Law
- State Charles’ Law
- State Gay-Lussac’s Law
- Give a mathematical statement of the gas laws
- State and use the correct units for pressure, volume and temperature
- Show how the three gas laws may be combined into one mathematical relationship.
- Understand how the gas laws relate to the transportation of natural gas
- Understand why the nominal gas pressure is high in some parts of the network and low in other parts
- Outline what is meant by the Joule-Thompson Effect and outline its implications for the gas network
- Outline the principle of network monitoring
- Describe the function of gas metering
- Explain the role of Bord Gáis.

General Learning Points

The following information can be used to review the lesson and inform discussion.

**Joule-Thompson Effect**

The **Joule-Thompson effect**, (or **Joule-Kelvin effect**), is a process in which the temperature of a real gas is either decreased or increased by letting the gas expand freely at constant enthalpy. The effect is named after James Prescott Joule and William Thompson. Thompson established the effect in 1852 following Joule’s earlier work on gas expansion.

When a real gas (as distinct from an ideal gas) expands freely at constant enthalpy, the temperature may increase or decrease. It will rise if the initial temperature is below a level called the Joule-Thompson inversion temperature and it will fall if the initial temperature is above the inversion temperature. For most gases at atmospheric pressure, the inversion temperature is fairly high (above room temperature), and so most gases at those temperature and pressure conditions are cooled by isenthalpic expansion.
### Student Activity

**Direct measurement of atmospheric pressure**

**Equipment:** 1 large plastic syringe (e.g. 25 or 50 cm³), a plug or seal for nozzle of the syringe, a 50 N spring balance, two lengths of strong twine, a ruler.

1. Push the plunger fully into the syringe. Plug the nozzle.
2. Tie or fix the spring balance to a strong anchor point. Tie the plunger of the syringe to the hook of the spring balance. It is best if the items can be arranged horizontally along a bench or table.
3. Hold the body of the syringe tightly and pull, gradually increasing the force until the plunger moves. Read and record the force \( F_1 \).
4. Pull the syringe further until the plunger is near the open end. And again read and record the force \( F_2 \).

**Caution:**
1. Be careful not to pull the plunger out completely.
2. Do not release the syringe until you have allowed the plunger to return fully into the syringe.

**Calculations**

Using the ruler, measure the distance in centimetres between the zero and the maximum on the syringe scale \( d \). Divide the stated volume of the syringe by this distance; this gives the cross-sectional area of the syringe \( A \). Alternatively, you could calculate the area using \( A = \pi r^2 \).

The pressure of the atmosphere \( P \) is equal to the force divided by the area: \( P = F/A \). If there was no air in the syringe at the start you should find that \( F_1 \) and \( F_2 \) are about the same.

### Examination Questions

**Leaving Certificate Chemistry (HL) 2007, Q. 10**

(b)  

(ii) Carbon dioxide is stored under pressure in liquid form in a fire extinguisher. Two kilograms of carbon dioxide are released into the air as a gas on the discharge of the fire extinguisher. What volume does this gas occupy at a pressure of \( 1.01 \times 10^5 \) Pa and a temperature of 290 K? What mass of helium gas would occupy the same volume at the same temperature and pressure?

(iii) Give one reason why carbon dioxide is more easily liquefied than helium.

**Leaving Certificate Physics (HL) 2006, Q. 12**

(a) Define pressure. Is pressure a vector quantity or a scalar quantity? Justify your answer.

State Boyle’s law.

A small bubble of gas rises from the bottom of a lake. The volume of the bubble increases threefold when it reaches the surface of the lake where the atmospheric pressure is \( 1.01 \times 10^5 \) Pa. The temperature of the lake is 4°C.

Calculate  

(i) the pressure at the bottom of the lake;  
(ii) the depth of the lake.  

(acceleration due to gravity = 9.8 m s\(^{-2}\); density of water = \( 1.0 \times 10^3 \) kg m\(^{-3}\))

**True/False Questions**

a) Steel pipelines are used for high pressure networks, whereas polyethylene is used for the low pressure local network.  
T F

b) Bord Gáis on-shore locations are sited in Co. Wicklow.  
T F

c) Boyle’s Law states that \( P_1V_1 = P_2V_2 \).  
T F

d) In the Bord Gáis network the term PRS means Private Regeneration Station.  
T F

e) When most real gases expand freely, the temperature decreases.  
T F

f) The bar is a unit of temperature.  
T F

g) Bord Gáis also provides electricity to customers.  
T F

h) The gas pressure in the undersea pipes is about 10 bar.  
T F

i) The unit of pressure is the newton.  
T F

j) Charles’ Law states that \( V_1/T_1 = V_2/T_2 \).  
T F

Check your answers to these questions on www.sta.ie.
Did You Know?

- The Joule-Thompson inversion temperatures of helium at one atmosphere is about -222°C very low. Therefore, the gas heats up when it is expanded at constant enthalpy. Hydrogen behaves similarly.
- The gas in the network passes through filters that can trap particles as small as a micron in size (1 micron = 10^-6 m = one thousandth of a millimetre). The operation of these filters is continuously monitored by the Bord Gáis SCADA system.
- Locations where filtering, regulating and metering operations are carried out are known as Above Ground Installations (AGI).
- Constant enthalpy means constant internal energy. This implies that no heat is transferred to or from the gas, and no external work is extracted.
- There are over 12,000 kilometres of pipeline in the Bord Gáis network.
- The gas processed at Gormanstown and Loughshinny comes from Moffat in North East Scotland. When it reaches Ireland the gas has travelled some 200 kilometres along undersea pipes.

Biographical Notes

**William Thomson (Lord Kelvin) (1824 –1907)**

William Thomson was born in Belfast in 1824. He was a gifted mathematician, physicist and engineer. He worked at Glasgow University experimenting on electricity and thermodynamics. He developed the Kelvin scale of absolute temperature. In recognition of his work he was given the title Baron Kelvin; the title refers to the River Kelvin which flows through the grounds of the University.

**James Prescott Joule (1818 –1889)**

James Joule was born in Salford, Lancashire, in 1818. He studied the nature of heat, and developed much of the thinking about heat, energy and mechanical work. His efforts led to the concept of the conservation of energy and to the theory of the first law of thermodynamics. The SI unit of energy, the joule (J), is named after him, as is Joule’s Law.

Revise the Terms

Can you recall the meaning of the following terms?

Reviewing terminolgy is a powerful aid to recall and retention.

ambient ground temperature, ambient temperature, bar, barometric, CH₄, fuel, gas constant (R), gas meter, heat exchanger, Joule-Thompson effect, kPa, liquefy, methane, mole, mole, MPa, newton, orifice, pascal, pressure, regulator valve, steel, temperature, volume

Check the Glossary of Terms of this lesson at [www.sta.ie](http://www.sta.ie).