Atmospheric Pressure

11.7

Have you ever felt your ears "pop" in an airplane or when driving over a hilly road? What you are experiencing is a change in air pressure. Like everything else near Earth, the atmosphere is under the influence of gravity. Gravity pulls this enormous mass toward the centre of Earth.

Pressure

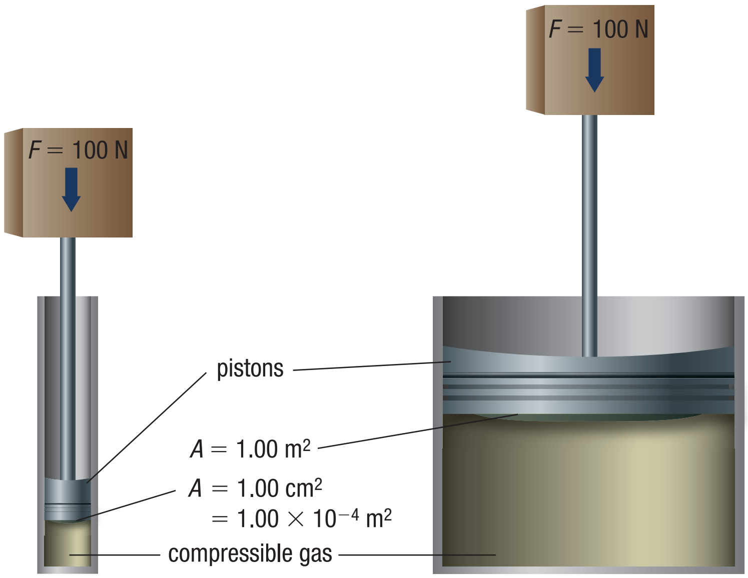
Pressure is defined as the force per unit area. Like volume and temperature, pressure is a physical property of a gas. As you will soon learn, there are many important applications of gas pressure. Before discussing air pressure specifically, we will consider a more visible example of pressure. **Figure 1** illustrates some of the factors that determine pressure. The gravitational pull of Earth exerts a downward force on everyone, including the person in Figure 1. As a result, he exerts a downward force on the nails. However, to minimize pain, this person would be wise to distribute this force over as large an area as possible. The greater the area, the lower the pressure. He would still exert the same downward force if he were to stand on one foot on the nails. However, the force would then be concentrated into a smaller area. The smaller the area, the greater the pressure.

Mathematically, pressure, P, is expressed as

$$P = \frac{F}{A}$$

The SI unit for pressure is the pascal (1 Pa = 1 N/m^2). Pressure is directly related to the size of force applied. The greater the force, the greater the pressure. Pressure is inversely related to area. A large force applied to a small area will produce a large pressure. If the same force is applied to a large area, the pressure will be less. For example, if a force 100 N were applied to an area of 1.00 cm^2 (0.000100 m^2 or 1.00×10^{-4} m^2), the pressure would be 1.00×10^6 Pa (**Figure 2(a)**). If the same 100 N force were applied to a much larger area of 1.00 m^2, the pressure would be only 100 Pa (**Figure 2(b)**).

Figure 1 The more nails there are, the less painful this experience will be.



$$P = \frac{100\ \text{N}}{0.000100\ \text{m}^2} = 1.00 \times 10^6\ \text{Pa}$$

(a)

$$P = \frac{100\ \text{N}}{1\ \text{m}^2} = 100\ \text{Pa}$$

(b)

Figure 2 The smaller the surface area on which the mass is resting, the greater the pressure exerted.

When a piston applies a pressure to a trapped sample of gas, as in Figure 2, the gas exerts a pressure on the walls of its container. It is the force exerted by the gas molecules as they collide with the inner walls of the container that results in the observed pressure. These collisions are what keep bicycle tires hard when they are inflated.

Measuring Atmospheric Pressure

atmospheric pressure the force per unit area exerted by air on all objects

standard pressure 101.325 kPa (often rounded to 101 kPa)

standard temperature and pressure (STP) 0 °C and 101.325 kPa

standard ambient temperature and pressure (SATP) 25 °C and 100 kPa

Atmospheric pressure is the force per unit area exerted by air on all objects. It is commonly reported in kilopascals, kPa. At sea level, the pressure exerted by a column of air with a base of one square metre is equal to 101.325 kPa (often rounded to 101 kPa). This pressure is known as **standard pressure** and is the basis for another unit of pressure: the atmosphere. One atmosphere is equal to 101.325 kPa.

Traditionally, chemists defined the standard conditions for work with gases as the temperature 0 °C and pressure 101.325 kPa. A gas sample at these conditions is said to be at **standard temperature and pressure (STP)**. However, since 0 °C is not a convenient temperature at which to conduct laboratory investigations, scientists have recently defined another set of standard conditions. These conditions are called **standard ambient temperature and pressure (SATP)** and are defined as 25 °C and 100 kPa. The SATP standard is more convenient than STP because it more closely represents the conditions in a laboratory.

Evangelista Torricelli (1608–1674) was the first person to devise a method of measuring atmospheric pressure. He was trying to solve a problem. Pump makers in Tuscany could not raise water more than 10 m using a suction pump. Torricelli used mercury, which is denser than water, to investigate the vacuum and atmospheric pressure. He prepared a glass tube similar to an extremely long test tube. He filled the tube with mercury and carefully inverted it, submerging the open end into a dish containing more mercury (**Figure 3**). The mercury in the tube was pulled down by gravity. However, the mercury did not all run out of the tube. Why not? Air pressure pushed on the mercury in the dish, effectively pushing mercury into the tube. A vacuum formed at the top of the tube. The vacuum exerted no downward pressure on the mercury inside the tube.

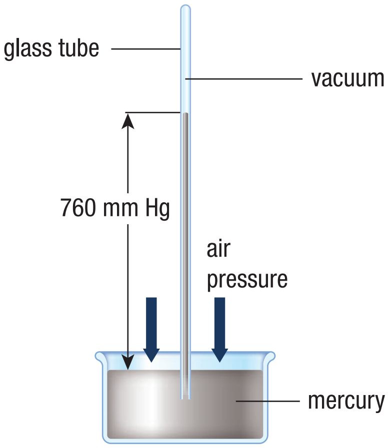


Figure 3 Torricelli's apparatus for measuring atmospheric pressure was based on the work of an earlier scientist: Galileo.

Torricelli noticed that the mercury level in the tube changed slightly from day to day. The fluctuating mercury level was due to changes in air pressure. This device for measuring atmospheric pressure became known as a barometer. At one time, the standard pressure was defined as 760 mm Hg or 760 Torr in honour of Torricelli.

Scientists had been investigating gases for many years before there was a standardized unit for pressure. Some scientists developed their own ways of measuring pressure. This is one reason we now have so many units for pressure. Some of these units are used in a specific situation. For example, medical professionals use mm Hg for measuring blood pressure. In Canada we still commonly measure tire pressure in psi (pounds per square inch), even though we use the metric system for many other quantities. **Table 1** shows the conversion of several SI and non-SI pressure units.

Table 1 SI and Non-SI Units of Pressure

Unit name	Unit symbol	Definition/conversion
pascal	Pa	1 Pa = 1 N/m^2
millimetres mercury	mm Hg	760 mm Hg = 1 atm = 101.325 kPa
torr	Torr	1 Torr = 1 mm Hg
atmosphere	atm	1 atm = 101.325 kPa (exactly)
pounds per square inch	psi	1 psi = 6895 Pa

Tutorial 1 Converting between Units of Pressure

Sometimes you are given a measurement of pressure in one unit, such as millimetres of mercury (mm Hg), and you need to convert it into a different unit, such as pascals (Pa). This is a fairly simple mathematical procedure. You can use the definitions in Table 1 to write conversion factors that allow you to switch from one unit to another.

Sample Problem 1: Converting from kPa to mm Hg

The average atmospheric pressure on Mars is 0.60 kPa. What is this value in mm Hg?

Given: $P = 0.60$ kPa

Required: pressure in mm Hg

Solution:

Step 1. Find the relationship between kPa and mm Hg (Table 1).

760 mm Hg = 101.325 kPa

Step 2. Write the relationship as a fraction, with the unit you want to find as the numerator.

$$\frac{760 \text{ mm Hg}}{101.325 \text{ kPa}}$$

Step 3. Multiply the given value by the conversion factor developed in Step 2.

$$0.60 \cancel{\text{kPa}} \times \frac{760 \text{ mm Hg}}{101.325 \cancel{\text{kPa}}} = 4.5 \text{ mm Hg}$$

Statement: The average atmospheric pressure on Mars expressed in mm Hg is 4.5 mm Hg.

Practice

1. Convert each of the following measurements of pressure to the units indicated: K/U
   (a) 203 kPa to mm Hg [ans: 1520 mm Hg]
   (b) 40.0 kPa to Torr [ans: 3.00×10^2 torr]
   (c) 717 mm Hg to Pa [ans: 9.56×10^4 Pa]

Figure 4 Most climbers need oxygen tanks to complete the final summit of Mount Everest.

Atmospheric Pressure and Altitude

More than 8000 climbers have attempted to scale Mount Everest, the highest mountain on Earth (elevation 8850 m). More than 2000 of these climbers have been successful, while more than 200 people have perished in the attempt. At least 120 bodies remain lost on Mount Everest. Reaching the summit is a gruelling journey. The cold and the rough terrain are certainly difficult, but the atmosphere presents its own challenge. The air density is low at this altitude, with less oxygen per unit volume than air at sea level. As a result, most climbers require oxygen tanks at high altitudes (**Figure 4**).

The density of gases in the atmosphere changes with altitude, decreasing as altitude increases (**Figure 5**). Greater gas density means more collisions per unit area and, therefore, higher pressure at Earth's surface. Like air density, atmospheric pressure decreases as altitude increases (**Table 2**).

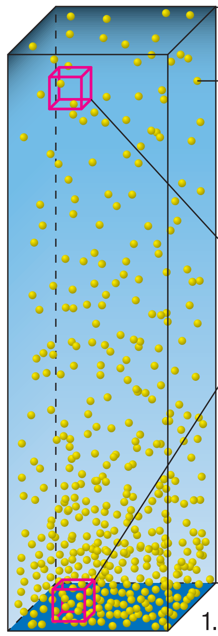


Figure 5 There are more entities in any given volume of air at sea level than in the same volume high in the atmosphere. The density of air is therefore greater at sea level than higher up.

Table 2 Typical Air Pressure at Various Altitudes above Sea Level

Location	Altitude (in m)	Air pressure (kPa)
Mount Everest (highest location on Earth)	8850	34
Mount McKinley (highest location in North America)	6194	48
Mexico City	2240	78
Calgary, AB	1049	90
Toronto, ON	112	100
Montreal, QC	57	101
Victoria, BC	49	101
Death Valley (lowest location in North America)	−86 (below sea level)	102
Dead Sea (lowest land location on Earth)	−413 (below sea level)	106

The change in atmospheric pressure is the reason why your ears sometimes hurt when you change altitude quickly. Your ear is a complicated organ designed to detect sound waves. The middle ear is an air-filled chamber that is isolated from the outside air by the eardrum and is connected to a channel called the Eustachian tube which vents into your throat (**Figure 6(a)**).

When a plane takes off and climbs higher in the sky, the atmospheric pressure in the cabin decreases. With less pressure on the eardrum, the volume of gas in the ear increases and presses the eardrum out. This gives the uncomfortable feeling of fullness in the ears. Fortunately, you can stop the discomfort by making the Eustachian tubes open up, allowing air to flow from the middle ear into the throat. This equalizes the pressure of the air in the middle ear with the atmospheric pressure in the plane. This venting is the "popping" sensation that you feel as your ears clear. Chewing gum, yawning, and swallowing all tend to make it easier for the Eustachian tube to vent air into your throat (**Figure 6(b)**). Aircraft designers have to factor this huge pressure change into their engineering plans.

CAREER LINK

To find out more about the work of an aircraft designer,

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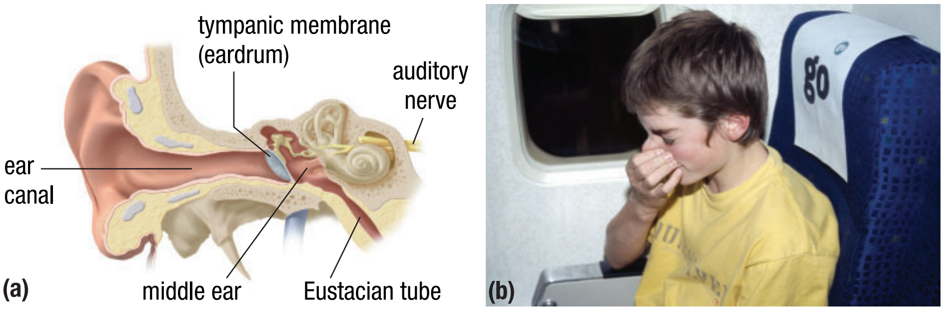

Figure 6 (a) A diagram of the ear (b) This is one way to clear your ears during air travel.

WEB LINK

To see a video of this tank being crushed,

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Atmospheric pressure can cause damage on a much larger scale. Railway tank cars are designed to withstand pressures that are higher inside than outside. If the pressure inside the tank were suddenly made much lower than the pressure outside, the atmospheric pressure would crush the tanks (**Figure 7**).

Figure 7 What happens when you reduce the internal pressure in a sealed vessel? (a) The interior of the steel tanker was heated. This expanded the air inside the tanker. The tanker was then sealed. (b) As the air inside cooled and contracted, the outward pressure it exerted could no longer match the pressure of the atmosphere—the tanker collapsed!

Mini Investigation

How Strong Is Your Pop Can? (Teacher Demonstration)

Skills: Questioning, Planning, Performing, Observing, Analyzing, Communicating   SKILLS HANDBOOK A1.2, A2.1

In this investigation you will explore the effect of atmospheric pressure on a pop can. You will boil water inside the can to produce water vapour. Then you will cool the can rapidly by placing it in a pail of water.

Equipment and Materials: chemical safety goggles; lab apron; plastic pail; graduated cylinder; empty aluminum pop can; beaker tongs; heat source (hot plate or Bunsen burner clamped to a retort stand); tap water

This activity may involve open flames and boiling water. Tie back long hair and secure loose clothing and jewellery.

1. Wearing chemical safety goggles and a lab apron, your teacher will fill a bucket three-quarters full with cold water.
2. An aluminum pop can will be filled with about 10 mL of water.
3. Your teacher will then hold the can over a heat source until the water boils.
4. The can will then be placed over the pail of water, inverted, and submerged in the cold water.
5. Observe any changes in the aluminum can.

A. How does heating the water in the can change the conditions inside the can? T/I

B. What effect does the water in the pail have on the conditions inside the can? T/I

C. Explain the changes that you observed when you inverted the can in the water. T/I

High-Altitude Training

Many endurance athletes train at high altitudes in an attempt to improve their performance. Some research shows benefits to this type of training, but other studies do not. When athletes train at high altitudes, they generally go to elevations above 2000 m where the air pressure is 77 to 80 kPa (Table 2, page 543). At this altitude there is still 21 % oxygen in the air but all atmospheric gases are at lower density. A lower density means that each breath contains less oxygen than it would at sea level. After three or four weeks the body compensates for lower oxygen levels by making more red blood cells to carry oxygen and producing more enzymes to utilize oxygen.

When athletes return to lower altitudes they may feel energized, having an increased ability to use oxygen. Not all athletes perform better after altitude training. Disappointing performance may result because the athlete cannot train as rigorously while the body adjusts to the higher altitude and lower oxygen level. Some endurance athletes live at high altitudes but train at low altitudes. They believe that this way they obtain the physiological advantages of high altitudes, but they can still train intensively.

WEB LINK

To check out an interactive graph that compares the concentration of atmospheric oxygen at various altitudes,

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To find out more about being an athletic trainer,

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11.7 Summary

- Pressure (P) is defined as the force (F) exerted per unit area (A).

$$P = \frac{F}{A}$$

- The SI unit for pressure is pascal (Pa). 1 Pa = 1 N/m^2
- Atmospheric pressure is the force per unit area exerted by air on all objects. Standard pressure (the pressure exerted at sea level by a column of air with a base of 1 m^2) is 101.325 kPa.
- Standard temperature and pressure (STP) conditions are 0 °C and 101.325 kPa.
- Standard ambient temperature and pressure (SATP) conditions are 25 °C and 100 kPa.
- The density of atmospheric gases is greatest at sea level.

11.7 Questions

1. Copy and complete **Table 3** in your notebook. K/U

Table 3 Equivalent Values of Pressure in Different Units

	Pressure (kPa)	Pressure (mm Hg)
(a)	58	
(b)		125
(c)	130	
(d)		950

2. (a) Define STP and SATP.
   (b) Explain why scientists have defined two sets of standard conditions.
   (c) Which standard is most frequently used, and why? K/U
3. Skydiving is a sport that requires specific equipment for the demands of the environment (**Figure 8**). According to the Canadian Sport Parachuting Association, oxygen is mandatory for jumps that exceed 4572 m. Explain why this is necessary. T/I A

Figure 8 At high altitudes, skydivers must wear oxygen masks.

4. Some athletes sleep in low-pressure tents prior to participating in an athletic event at a high altitude. How is this likely to improve athletic performance? Do you think this is likely to be more or less effective than high-altitude training? Explain. K/U A
5. Modern aircraft have pressurized cabins. T/I A
   (a) What is meant by "pressurized cabin"?
   (b) What can occur if pressure is lost in the cabin?
6. The Summer Olympic Games were held in Mexico City in 1968. They produced some interesting results. The performance of many endurance athletes fell short of expectations. Many events that involved jumping and throwing, however, produced better than expected results. Use the data in Table 2 to help explain these results. A
7. (a) Create a graph of air pressure against altitude, using the data in Table 2. Label each of the locations on your graph.
   (b) Describe the trend in the data. Suggest an explanation for this trend.
   (c) Research the altitude and typical air pressure where you live, and add it to the graph. K/U C A
8. Research altitude sickness. What are the symptoms? Explain this phenomenon. T/I A
9. Research how air is used in pneumatic nail guns. T/I C A
10. High-pressure injectors, sometimes called jet injectors or hypospravs, are used to inject vaccines and other medicines under the skin of patients without using a needle. Research how these devices work and the benefits and drawbacks associated with their use. T/I A

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