Altitude and the Universal Gas Constant R

Apparatus

Atmospheric Pressure Sensor

EasySense App

Some altitude!

A dry day!

Data Recording Setup

Snapshot

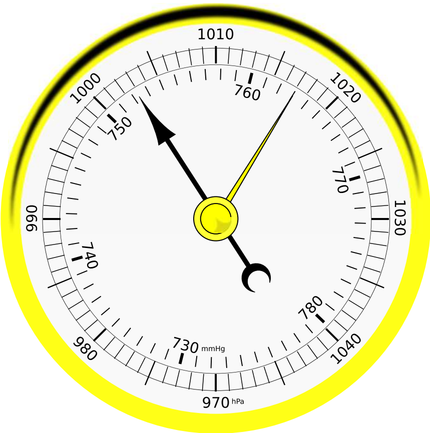
Introduction

Atmospheric pressure is a result of all of the atmospheric gas pressing down on the Earth's surface. So above you, there is a fair amount of atmospheric gas that is held in place by Earth's gravitational pull. You might be surprised just how much that is: it would support a column of water about 10 m in height and is enough to lift a an aeroplane well over 500 tonnes in mass.

What atmospheric pressure measurement shows is, as you go up in altitude, then the pressure declines (as there is less gas pressing down). So, atmospheric pressure when used properly, can be used to work out the altitude above sea level. This is how aircraft can work out how high they are.

But how quickly does the pressure fall with height above sea level? If you ever decide to go and climb Mount Everest, it will be wise to take an oxygen supply with you as the air gets a little "thin" at 8,800 m!

What we are going to do, is to see how the altitude affects the atmospheric pressure. There is some maths involved in the practical if you wish to look at that as well, and it helps us understand just how particles are distributed within a gravitational field.



Atmospheric pressure, along with temperature, humidity and wind direction are key elements in weather forecasting.

An atmospheric sensor can tell us some very fundamental things about the pressure changes going on around us.

Method

1. Turn on the Atmospheric Pressure Sensor.
2. Connect to the EasySense App, using the Devices Icon.
3. Select Atmospheric Pressure. You don't need to use the altitude option, you will need to know far above sea level each of your measurements are. So, some planning might be good idea!
4. Using Setup, select Snapshot
5. Collect data (Press Start) for altitude and atmospheric pressure. Try to make "sea level" or zero, the first point that you make. Record the starting position (nominally sea level) at the end of the run also. If this compares very well with the first point, then no time correction is needed.
6. Log the data in the table, if that helps. You can only fill in columns 1 to 4 when you are collecting.
7. Press Stop to finish. Make the last measurement sea level again so that we can see how consistent the data is.

Data

Time Elapsed / s	Altitude / m	Altitude (from zero position)/ m	Measured Atmospheric Pressure/kPa	Pressure Drift/kPa	Corrected Atmospheric Pressure/kPa

Results

What we can do is plot atmospheric pressure vs. altitude and see if there is a relationship.

It may be that as time has progressed, the atmospheric pressure has changed a little (drift). By looking at the start and end points and seeing how long it took you to do the entire experiment, a small drift factor can be introduced. If there is very little difference, then a drift correction isn't required.

Pressure at start (sea level) - Pressure at end (sea level) = A

Total Elapsed Time = B

Drift Correction = A / B

Pressure Drift (at time T) = Drift Correction × Time Elapsed

So each pressure reading could be corrected:

Corrected Atmospheric Pressure = Measured Atmospheric Pressure + Pressure Drift (at time T)

Analysis

What type of variation do you observe with pressure against altitude?

Why do you think you see happening with the data you have?

Extensions

What assumptions are there in the pressure drift factors?

Did you need to do a pressure drift correction?

If you used a Drift Correction, is there a better way of doing it?

Plot the ratio of the altitude pressure compared to sea level value vs. altitude. Does it give a straight line? Ask your instructor what this means for working out the Universal Gas constant!

Teacher and Technician Sheet

What we need to do is take measurements with altitude. It is best to choose a low humidity day.

The exercise does need a bit of planning, so if there is a chance to make use of some elevated positions - that will greatly assist the demonstration of pressure with altitude. The choice of the “sea-level” (or zero) altitude pressure, P_{sl} doesn’t have to be precise, but it should be the value that you reference to.

A drift correction factor might be needed if P_{sl} varies over a relatively long experiment. The assumption is that as time goes on, the correction is simply a linear adjustment to allow for pressure drift. A better way to do it is to take more baseline measurements between readings.

What we observe from a Boltzmann energy distribution in a gravitational field, is a pressure variation with altitude:

$$P_{alt} = P_{sl} \exp[-mgh/(kT)]$$

Here, P_{alt} is the pressure at altitude, k is Boltzmann’s constant (1.38×10^{-23} m^2 kg s^{-2} K^{-1}), T = 290 K, m is the mass of a nitrogen molecule (mostly the air’s composition, 4.67×10^{-26} kg), g is acceleration due to gravity 9.81 m s^{-2}.

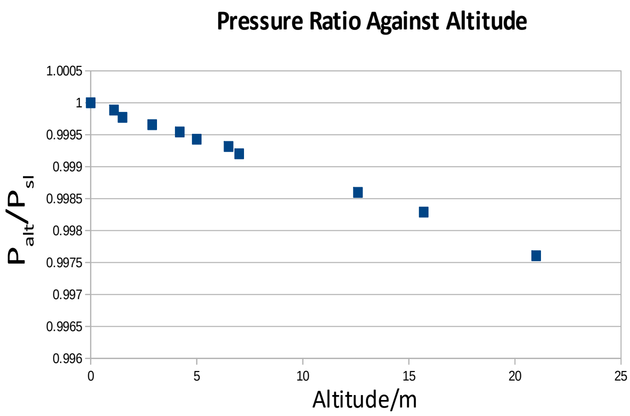
The term mg/(kT) is approximately equal to 1.14×10^{-4} m^{-1}. From the above equation,

$$P_{alt}/P_{sl} = \exp[-mgh/(kt)]$$

Or, if h is small then we can approximate this to:

$$P_{alt}/P_{sl} = 1 - mgh/(kt)$$

A plot of P_{alt}/P_{sl} against h should give a slope of mg/(kt). We can calculate the Boltzmann constant and then the Universal gas constant R (by multiplying that by Avogadro's number, 6.023×10^{23} mol^{-1}).



Thanks to the MK Dons for allowing us to measure in Stadium MK

The graph shows the ratio against height plotted from the above at 15 °C.

The slope is 1.21×10^{-4} m^{-1} which yields a value for k of 1.5×10^{-23} m^2 kg s^{-2} K^{-1}.

Using Avogadro's number, R = 9.06 J mol^{-1} K^{-1}. The reported number for R is 8.314 J mol^{-1} K^{-1}, so the comparison is very good considering experimental errors and the range of altitudes open to us!

Software knowledge Required

Connecting the sensor to EasySense (Devices) and selecting pressure

Using Setup to run a Snapshot experiment

Export the data (CSV) for further analysis