Isothermal and adiabatic processes

Question 1: Part 1

Isothermal changes

Air is enclosed in a small 10 ml plastic syringe. Motion and pressure sensors are used to plot pressure and volume on the PV diagram shown. Position data is converted to volume in a new calculated column in Logger Pro. The units of volume are arbitrary and the origin is not shown.

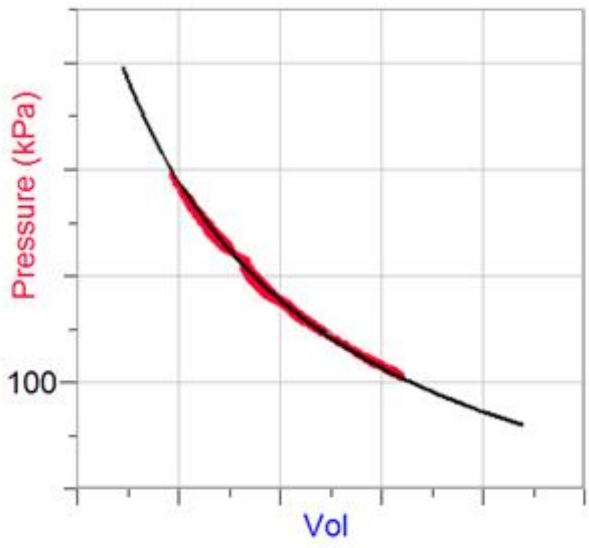

Fig 1 - A slow compression/expansion cycle begins at one atmosphere pressure.

a Sketch and label a diagram showing a possible arrangement of components for this demonstration.

b In your experience: how slowly must the piston be moved to plot the graph in figure 1?

c The black hyperbola is an *isotherm*. Briefly explain what is meant by an *isothermal process* and describe the cycle that begins at one atmosphere pressure.

d At what times during the cycle is heat flowing into and out of the enclosed air?

Question 1: Part 2

Adiabatic changes

The piston is now moved in and out more quickly. The data plot becomes a loop (figure 2). The units of volume are arbitrary and the origin is not shown.

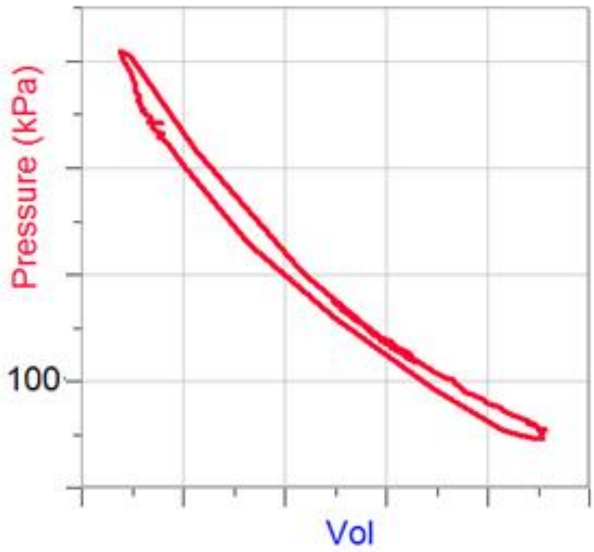

Fig 2 - The graph shows one rapid compression/expansion cycle that begins at close to one atmosphere pressure.

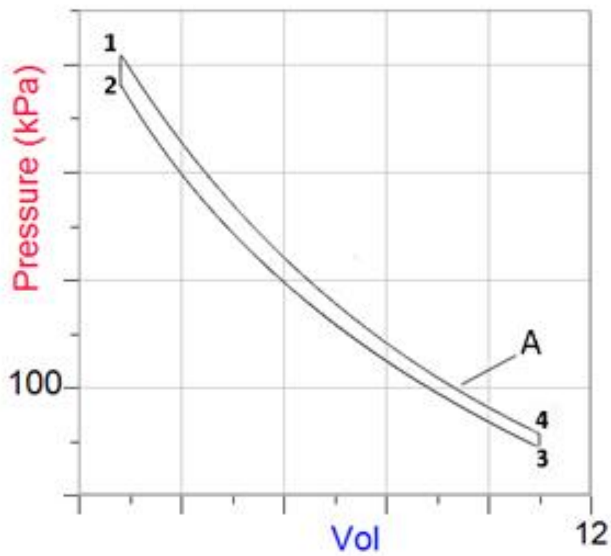

Fig 3 - The cycle shown in figure 2 redrawn as a diagram.

Rapid compression from A to 1 does work on the trapped air and the temperature rises. As the volume is kept constant (1-2) the warmed air cools to room temperature and the pressure falls. Rapid expansion from 2 to 3 leads to further cooling. Holding the volume constant (3-4) allows the gas to return to room temperature.

Question 1: Part 2

a Explain briefly what is meant by an *adiabatic* process?

b At what points on the diagram is the temperature highest and lowest?

d What two points in figure 3 lie on the same isotherm?

e The low-pressure end of the loop in figure 2 is a close approximation to the idealized diagram (figure 3). The high-pressure end is not. Look carefully at figure 4 below and suggest a reason for the difference.

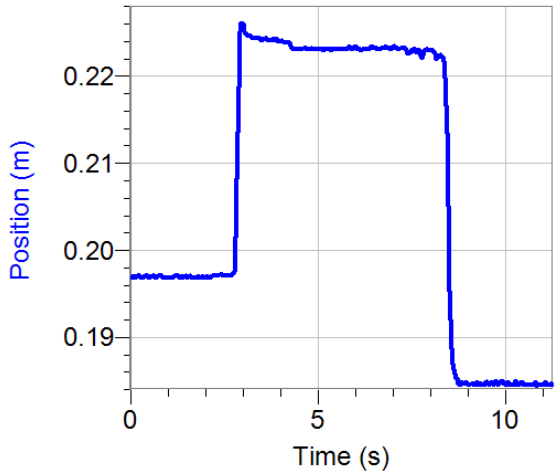

Fig 4 - The position–time plot.

Question 1: Part 3

The advice given to teachers when plotting these cycles by hand is to use a small syringe (3-5 ml) for figure 1 and a larger syringe (50 m) for figure 2.

a Explain briefly why it is suggested that the smaller syringe can be used for figure 1 but the larger one is preferred for figure 2.

Question 2: Part 1

Fig 1 – A student is going to step on the bottle in these shoes.

A student is demonstrating the effect of pressure changes in saturated air by stepping on and off the closed PET bottle shown in figure 1.

a Why did the teacher ask the students to put a little water in the bottle and to burn a slip of paper in it before screwing on the top?

b Why did the teacher ask them to step on the bottle and *wait for five seconds* before stepping off?

c What happens in the bottle when they suddenly step off it?

d Why was the bottle put on a dark background?

Question 2: Part 2

a Assume the plastic doesn't stretch during the compression and there is almost no volume change. *Estimate* the pressure increase in the bottle when half the student's weight is put on one foot on the bottle.

b Use the ideal gas equation to estimate the maximum possible temperature change inside the bottle.

c Why is the actual temperature change less than your estimate? (Two reasons.)

Question 2: Part 3

Fig 2 – Pileus cloud over a rising cumulus cloud at sunset

The wide cap-cloud is formed as air flows up and over the cumulus cloud.

a How are the processes in the bottle related to the formation of pileus clouds in the atmosphere?

Question 3: Part 1

Engines and compression ratios

The compression ratio for petrol (gasohol) engines is more than 7 and less than 12. Diesel engines have higher ratios around 20, and a fire piston (look it up) may have a compression ratio as high as 25.

a What exactly is meant by *compression ratio*?

b Why do diesel engines (that have no spark plugs) require a higher compression ratio than petrol engines that have spark plugs?

c Pre-ignition (detonation) is sometimes an issue with petrol engines. What causes detonation?

d Tetraethyl lead was once added to petrol to reduce detonation. Why did lead do that and why was its use discontinued?

Question 3: Part 2

Lapse rates in the atmosphere

The average *lapse rate* (the measured reduction in temperature with altitude in stable air) is 0.65 ºC per 100 m from sea level to about 10 000 m. The lapse rate is almost the same everywhere. The adiabatic cooling rate when a parcel of dry air rises is 0.98 ºC per 100 m, higher than the lapse rate.

a Knowing this, explain why a parcel of rising warm dry air soon stops rising.

In Thailand air at ground level is never dry. A rising parcel of saturated air cools at 0.60 ºC per 100 m.

b Knowing this, explain why a rising parcel of saturated air keeps rising. In other words: why do rising cumulus clouds keep rising to 10 000 m?

c Explain briefly where the heat comes from to keep rising saturated air warmer than the surrounding air?

Question 3: Part 3

Saturated air

The *mixing ratio* of water vapor to air in g/kg for saturated air changes with temperature. In the tropics the change in mixing ratio is nearly linear with altitude between sea level and 2000 m. The values are ~19 g/kg at sea level, ~15 g/kg at 1000 m and ~9 g/kg at 2000 m.

See … http://images.slideplayer.com/16/5124616/slides/slide_23.jpg

a Suppose the top of the rising cumulus cloud shown in figure 2 above was at 1500 m and the airstream over the cloud rose at most 250 m. Use mixing ratios and the density of air at 1500 m (1.05 kg/m^3) to *estimate* the water content of the pileus cloud per cubic metre.

b Estimate the warming effect of condensation from saturated air at 1500 m. Take the latent heat of vaporization of water as 2,260 kJ/kg and the heat capacity of air as 1000 J/kg.