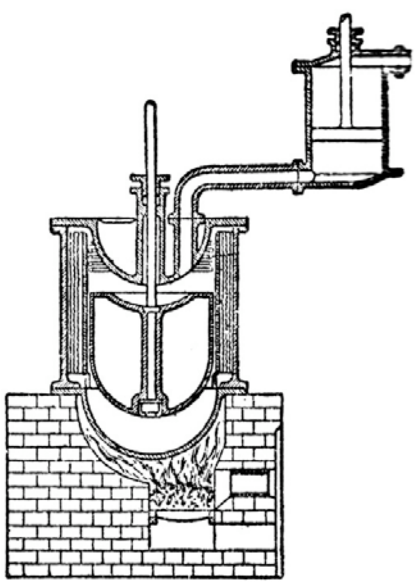
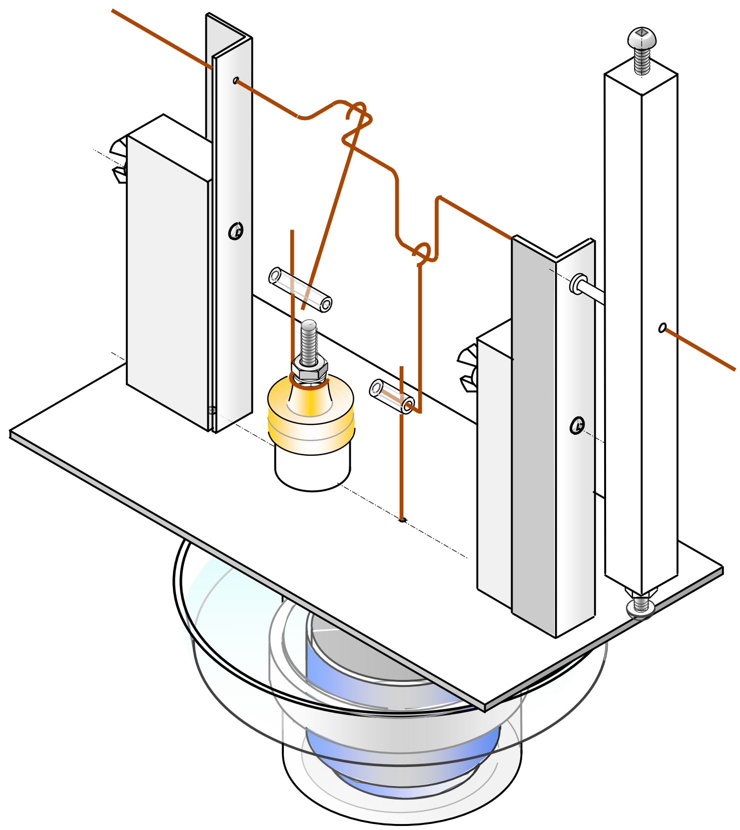
centre de
développement
pédagogique
pour la formation générale
en science et technologie

Working document

THE STIRLING ENGINE





TEACHER AND TTP GUIDE

January 2009

Table of contents

NOTE	**This activity was designed within the framework of teacher training sessions. It will require adaptation before being used with students.**

Historical video on the Stirling engine

The essentials of science (e=m6)

Those unusual inventions!

The Stirling engine…

Available on the Web

http://www.amazon.fr/E-M6-Ces-inventions-insolites/dp/B000AP1L5I/ref=sr_1_19?ie=UTF8&s=dvd&qid=1236624017&sr=8-19

Kinetic theory of gases

Question: How do gases behave?

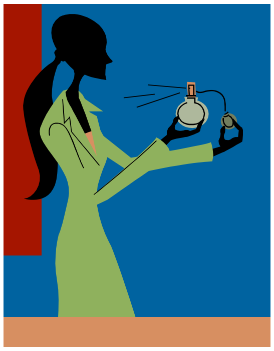
Observe the demonstrations and complete the following texts in such a way as to remember the essential facts.

Expansion of a gas (molecular movement of gases)

Demonstrations on translation, rotation and vibration movements.

The molecules of a gas are like little **marbles** that move in all directions. Normally, these particles move in a **straight** line unless they hit other gas, liquid or solid particles. In this way, gases always **fill** their container, taking all the available space. The soccer ball shown here to the left is a good example of this. Finally, a gas has neither a precise **form** nor volume, contrary to solids, for example.

Diffusion of a gas



Demonstration of the diffusion of a soft perfume in the class.

Gas molecules move in **all** directions. A certain gas can in this manner, spread throughout another gas. The **diffusion** of a gas in a room may take a certain time. How many seconds does it take for the **perfume** to get to your nostrils? What do you do if the **odour** becomes unsupportable?

Compression of a gas

Demonstration on the quantity of gas that can come out of an aerosol can.

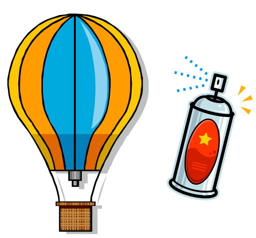
Contrary to **liquids**, gases are compressible. It is possible to make the **volume** of a gas vary considerably by modifying the pressure exerted upon it. This increase in **pressure** brings the molecules closer to one another. That is why you can inject a large volume of air into a **small** bicycle air chamber, for instance.

Pressure of a gas

Demonstration of the implosion of a metal can filled with water vapour.

The **atmospheric** pressure that we are currently subjected to is the result of innumerable collisions that occur between air molecules and our body. Each air molecule that **hits** us has a mass and a speed and produces a small thrust on our skin. It is the sum of all these small **thrusts** that generates atmospheric pressure. In the case of air compressed into a diver's tank, these collisions are **more** numerous since the molecules are condensed into a smaller volume. The pressure is a measure of force per unit of surface (Newtons per square meter, for instance).

Heating a gas



Demonstration of heating on a black garbage bag filled with air, then lit with a lamp.

The hot air balloon to the left here reminds us that heating a gas causes an **increase** in its volume. In addition, everyone knows that it's not a good idea to throw an aerosol container into a fire. The increase in temperature would cause an **increase** in the pressure of the gas.

Number of molecules and volume of a gas

Questions: How does the number of gas molecules (the number of moles) vary when we make the volume of a gas vary? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes? What should remain constant throughout the experiment? How can this study bring you to a better understanding of the Stirling engine?

Prove experimentally and show mathematically

The security capsule below may be distributed to the students.

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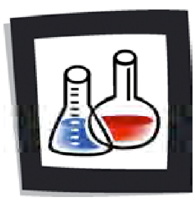
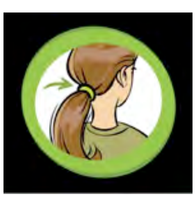
Security capsules

(12) Acid solutions




1. Be careful! Acids are corrosive substances.
2. Wear safety glasses to protect yourself from splashes. In case of contact with eyes, rinse immediately with the ocular wash in the classroom.
3. Tie long hair back and be careful of your sleeves in order to avoid spillage or contact with the acid.
4. Never smell emanations directly. Fan the vapours towards your nose with your fingers.
5. Wear protective clothing against accidental projections.
6. Wash skin with water in case of contact and wash your hands at the end of manipulations.
7. Wipe the work surface well after manipulations to remove possible splashes.
8. Take the time to think about each of your gestures.

Ensure that any modifications to this capsule do not compromise student safety. Any person found to be at fault will have to assume their choices.




Directed laboratory

Data table (example)		
	Mass of magnesium (gram)	**Volume of hydrogen (millilitre)**
2 cm. piece of magnesium	*0,018*	*19*
3 cm. piece of magnesium	*0,027*	*30*
4 cm. piece of magnesium	*0,036*	*36*
5 cm. piece of magnesium	*0,045*	*55*
6 cm. piece of magnesium	*0,054*	*58*
20 cm. piece of magnesium	*0,180*	

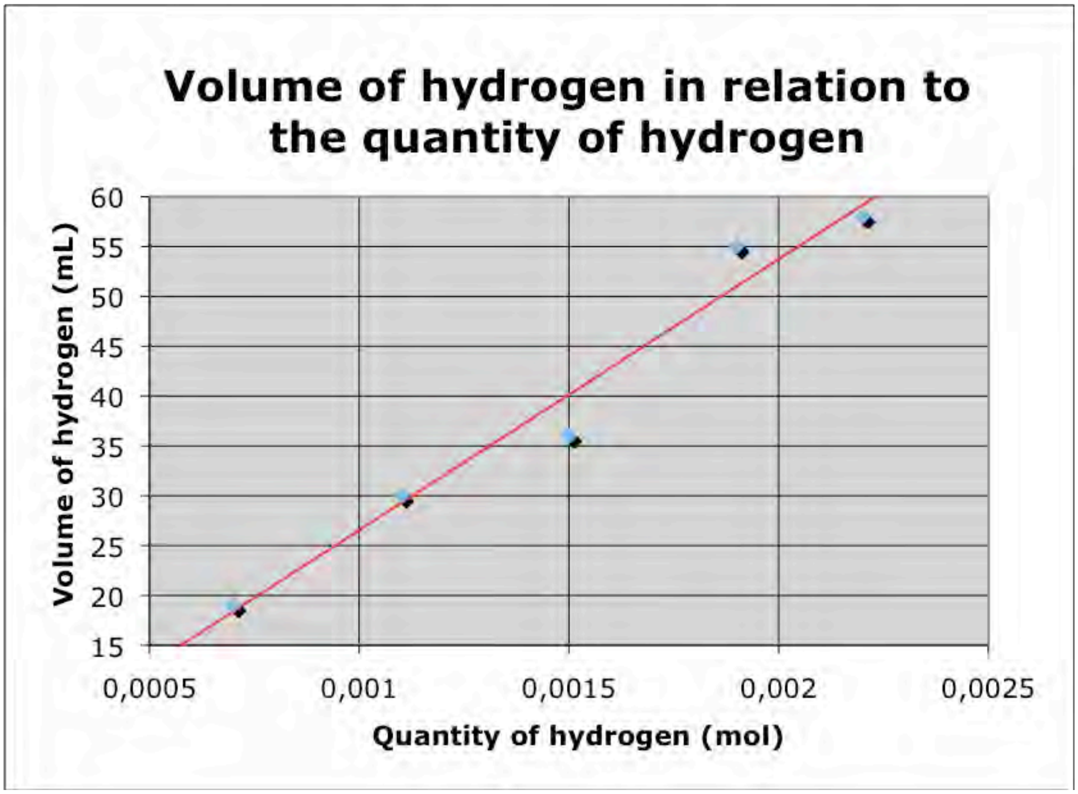
Analyse the results (example)

Process your data

Question 1 $Mg_{(s)} + 2\ HCl_{(aq)} \longrightarrow MgCl_{2(aq)} + H_{2(g)}$

Question 2 See the quantities of hydrogen calculated in the table below.

	Quantity of hydrogen (mole)
2 cm. piece of magnesium	*0,0007*
3 cm. piece of magnesium	*0,0011*
4 cm. piece of magnesium	*0,0015*
5 cm. piece of magnesium	*0,0019*
6 cm. piece of magnesium	*0,0022*



Emphasise the tendencies

Question 3

It is a linear mathematical relation.

Question 4

Rate of variation ≈ 27182.3 mL/mol (ordinal at the beginning: -0.63)

Draw your conclusions

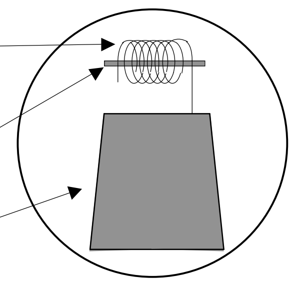
Question 5

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

Question 6

By increasing the interior volume of gas in the Stirling engine, the number of gas atoms available to do the work would be greater. The engine would thus be more powerful.

Preparation of the material (Number of molecules and volume of a gas)

Material	Sketch of the assembly
• Protective glasses • 1 - #5 stopper **(not watertight on the cylinder)** • 15 cm of #18 copper wire • 1 ruler • 1 pair pliers for cutting • 1 pencil • 1 pin	

Method for preparing the copper wire:

1. Roll the copper wire around a pencil in order to form a spring shaped support.
2. Make a small hole to a depth of about 5 mm using a pin on the inside (small diameter) of the rubber stopper.
3. Push one extremity of the copper wire into this hole and mold the wire to form a support for the magnesium as in the sketch above.

Remarks:

- The #5 stopper used here must allow the acid solution to drain into the beaker. Usually, the lip of the cylinder ensures that the opening is not completely sealed and that is ideal. In some cases, it may be necessary to use a #5 stopper with one hole in it. Be careful not to make the opening too large because air could then enter when the cylinder is inverted.
- Plan to have containers in which to recover the acids in order to dispose of them adequately after the manipulations (either at the workstations or at the teacher's desk).
- It is important to perform the inversion of the cylinder a few times with water before doing it with acid.

The effect of temperature on the volume of a gas (Charles Law[1])

Questions: What is the effect of a variation in temperature on the volume of a gas? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes?

Prove experimentally and show mathematically.

The security capsule below may be distributed to the students.

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Security capsules

(10) Heating plate




1. Be careful of burns: the plate can stay hot a long time.
2. Tie long hair back and be careful of your sleeves in order to avoid them coming into contact with the plate and catching fire.
3. Wear safety glasses to protect yourself from projections.
4. Wear protective clothing against accidental projections. (Never direct the opening of a test tube towards yourself or anyone else.)
5. Use the appropriate tongs to manipulate the laboratory glassware (tongs for beakers, test tubes, etc.)
6. Take the time to think about each of your gestures.
7. Know where the safety equipment is and learn how to use it (fireproof blanket, fire extinguisher, eyewash, fire alarm, etc.)
8. Never use flammable substances near a flame or a hot heating plate.



Ensure that any modifications to this capsule do not compromise student safety.
Any person found to be at fault will have to assume their choices.

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[1] In certain works, the laws of Charles and Gay-Lussac are not associated to the same relations linking volume, pressure and temperature. The historic contribution of each of these scientists does not seem to be recognized the same way by all authors.

Directed laboratory

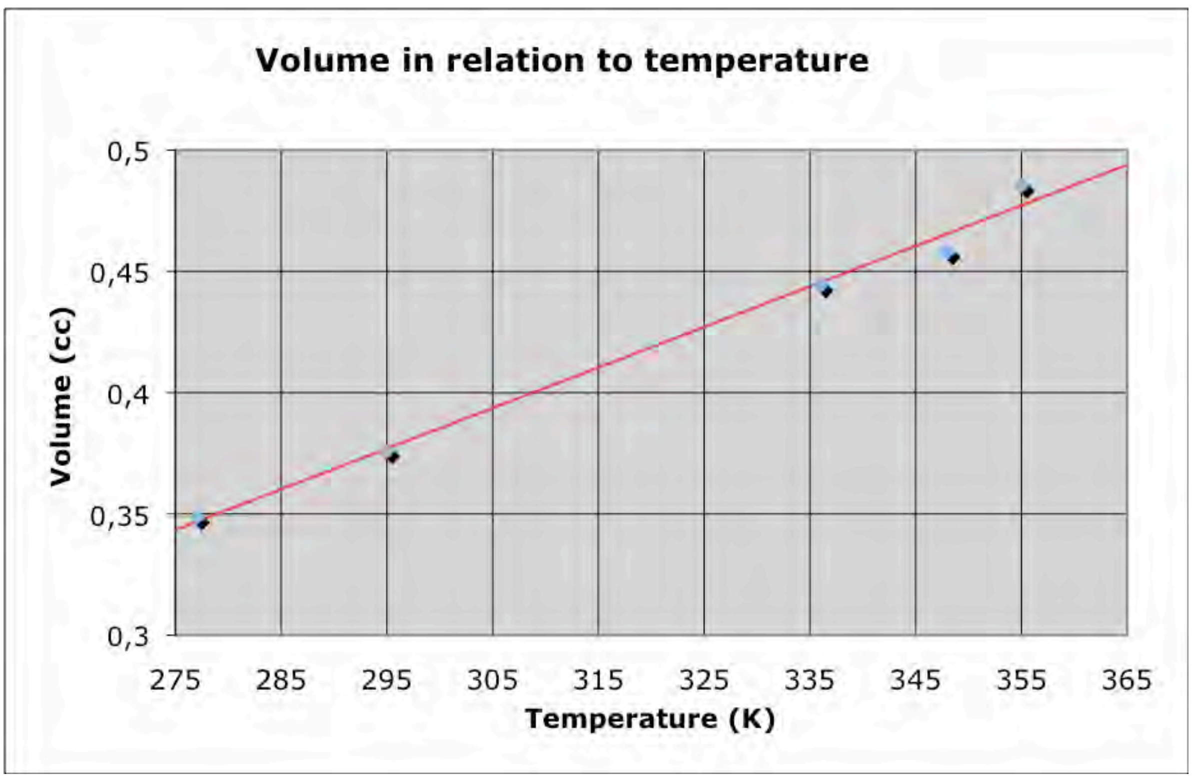
Data table (example)		
	Temperature of the imprisoned air (°C)	**Height of the volume of imprisoned air (cm)**
In melting ice	*4*	*5,1*
At room temperature	*22*	*5,5*
At about 50 °C	*63*	*6,5*
At about 75 °C	*75*	*6,7*
In boiling water	*82*	*7,1*

Analyse the results (example)

Process your data

Question 1 See the temperatures and volumes calculated in the table below.

	Temperature of the imprisoned air (K)	Volume of imprisoned air (cm^3)
In melting ice	*277*	*0,349*
At room temperature	*295*	*0,376*
At about 50 °C	*336*	*0,444*
At about 75 °C	*348*	*0,458*
In boiling water	*355*	*0,485*



Analyse the results (example)

Emphasise the tendencies

Question 2
It is a linear mathematical relation.

Question 3
The rate of variation is: 0.0017 cm^3/K (ordinal at the beginning: -0.1162)

Draw your conclusions

Question 4

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Question 5
In our case, -204 °C (69 K) (should be close to -273 °C or 0 K)

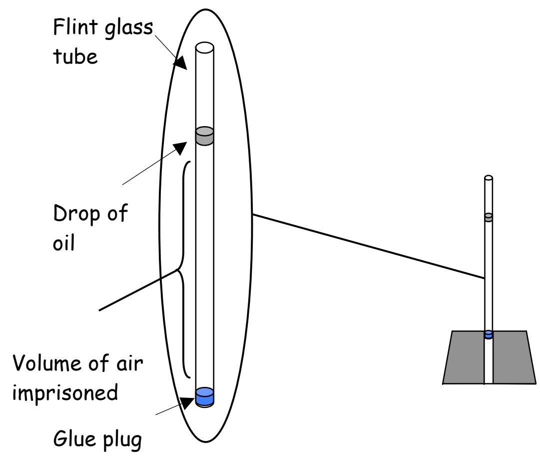
Question 6
To zero degrees Kelvin (absolute zero).

Question 7
T = 273 + (-10) = 263 K

Question 8
There are never negative values.

Question 9
$T_2 = V_2 * T_1 / V_1$
$T_2 = 1\ L * 300\ K / 10\ L$
$T_2 = 30\ K$

Preparation of the material (Effect of temperature on the volume of a gas)

Material	**Sketch of the assembly**
• Safety glasses • 1 – 5 mm diameter, 10 cm long tube of flint glass • 1 glass cutter • 1 ruler • Epoxy glue for the glass • Mineral oil • 1 eye dropper	

Method for preparing glass tube:

1. Add a drop of mineral oil to the glass tube.
2. Make the drop of oil slide by tilting the tube. The drop should go about one quarter of the total length of the tube (see sketch of the assembly).
3. Block the clean end of the tube using a drop of hot glue.
4. Insert the glass tube into the hole in the rubber stopper. Be sure to align the glue plug with the edge of the stopper.

If the teacher is planning to use boiling water, foresee longer glass tubes so that the oil does not spill over.

The effect of pressure on the volume of a gas (Boyle-Mariotte's Law)

Questions: What is the effect of a variation in pressure on the volume of a gas? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes?

Prove experimentally and show mathematically.

Directed laboratory

Data table (example)		
	Mass (g)	**Volume of air (mL)**
1	**100**	***0.44***
2	**200**	***0.34***
3	**300**	***0.28***
4	**400**	***0.22***
5	**500**	***0.19***

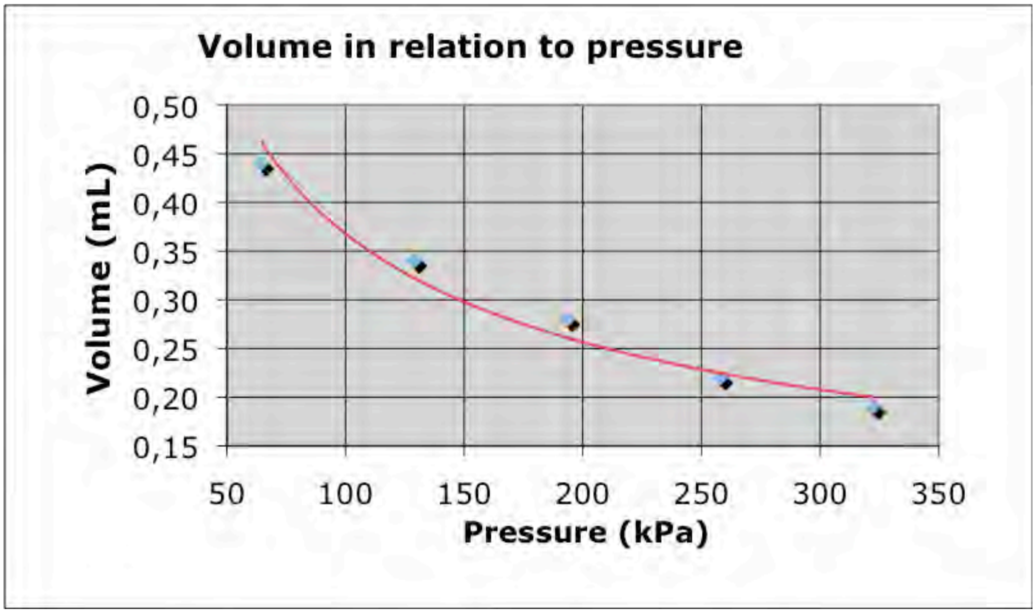
Analyse the results

Process your data

Question 1 See the forces calculated in the table below.

Question 2 See the pressures calculated in the table below.

Mass (g)	Force (N)	Pression (kPa)
100	***0.98***	***64***
200	***1.96***	***129***
300	***2.94***	***193***
400	***3.92***	***258***
500	***4.90***	***322***



Emphasise the tendencies

Question 3

It is an inverse mathematical relation.

Question 4

If we prolong the curve to a very small volume, the pressure should become very high.

Draw your conclusions

Question 5

$$p_1 . V_1 = p_2 . V_2$$

Question 6

When the volume quadruples, the pressure becomes four times smaller.

Question 7

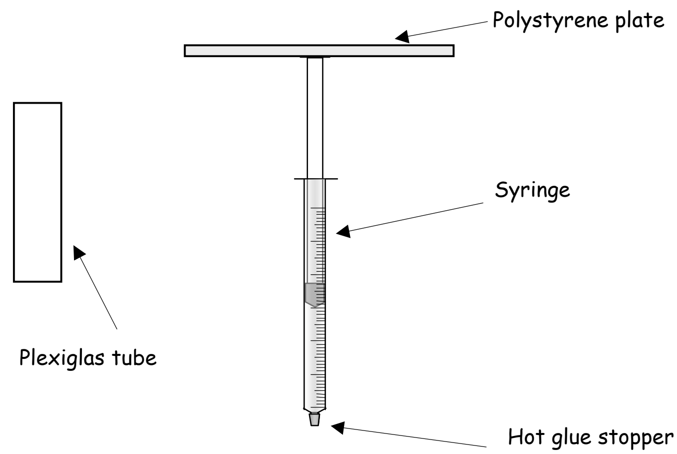
$$\frac{101.325 \text{ kPa}}{? \text{ kPa}} = \frac{760 \text{ mm of Hg}}{800 \text{ mm of Hg}}$$

A pressure of 800 mm of Hg therefore corresponds to 106.658 kPa.

Question 8

(Data)	**(Equation)**	**(Calculation)**
V_2 = ? mL p_1 = 101.3 kPa V_1 = 40 mL p_2 = 198.5 kPa	$p_1 . V_1 = p_2 . V_2$ $V_2 = p1 . V_1 / p_2$	V_2 = 101.3 kPa . 40 mL / 198.5 kPa **(Answer)** V_2 = 20,4 mL

Preparation of the material (Effect of pressure on the volume of a gas)

Material	**Sketch of assembly**
• Safety glasses • 1 - 1.6 cm diameter, 7 cm long Plexiglas tube • 1 – 3mm thick piece of polystyrene • 1 plastics knife • 1 saw and mitre box or band saw. • 1 ruler • 1 hot glue gun • 1 – 1 mL graduated syringe • 1 syringe cap or a little hot glue	

Method for preparing the syringe:

1. Cut a 6X6 cm. plate of polystyrene.
2. Affix the polystyrene plate to the syringe plunger using hot glue.
3. Completely withdraw the plunger from the syringe and obstruct its end with a cap or with a hot glue plug. (Wait for the glue to solidify).
4. Replace the plunger and push it all the way down.
5. Cut a Plexiglas tube 7 cm. long (the cut may be made with a saw and mitre box or with a band saw).

Function of a liquid column pressure gauge (optional)

Question: What variations in pressure (in kPa) can a 60 centimeter U shaped tube liquid column pressure gauge measure?

Work out with the help of a demonstration and show mathematically.

Directed laboratory

Notes

- This study of the liquid column pressure gauge is optional. To successfully complete it, the student must manipulation a large number of mathematical equations. **You can still use this kind of pressure gauge in the laboratory without studying it. In this case, an equation gives you the pressure directly in kPa. This equation appears in question 5 of the section entitled "Draw your conclusions" below.**
- The pressure measured by such a gauge is relatively low. In fact simply by blowing with your mouth, it is easy to eject the coloured water from the U shaped tube. Using an ordinary straw proves this fact.
- By lightly pressing the balloon, the coloured water rises on the free side of the U shaped tube. When the pressure is released, the level of water returns to its initial height.

Analyse the results

Question 1 $F_g = m \cdot g$ **(equation 1)**

Question 2 $\rho = m/V \Rightarrow m = \rho \cdot V$ **(equation 2)**

Question 3 $F_g = \rho \cdot V \cdot g$ **(equation 3)**

Question 4 $V = h \cdot S$ **(equation 4)**

Question 5 $F_g = \rho \cdot h \cdot S \cdot g$ **(equation 5)**

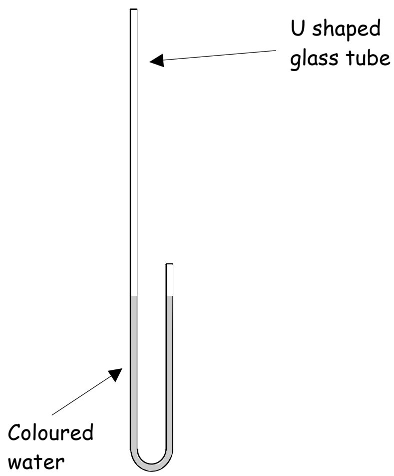
Question 6 $p = F_p/S \Rightarrow F_p = p \cdot S$ **(equation 6)**

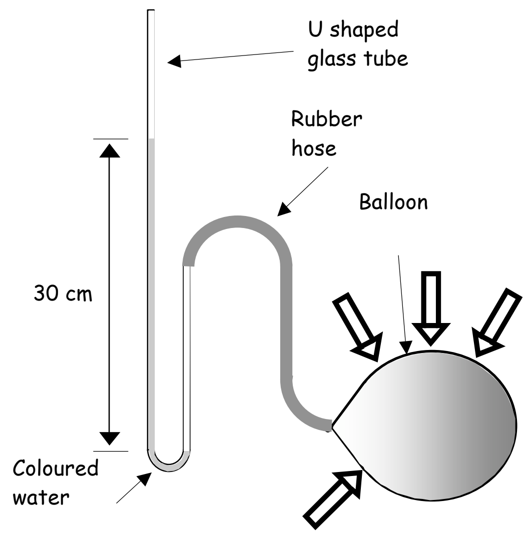
Question 7 $F_g = F_p$

$\rho \cdot h \cdot S \cdot g = p \cdot S$ **(equation 7)**

Question 8
You can note here that the section (surface) of the "**S**" tube is present on each side of the equation. It is therefore possible to simplify equation 7 by removing the variable "**S**" from each side. Concretely, this means that the section of the tube has no influence on the height attained by the coloured water. The size of the tube is immaterial. The equation therefore becomes: **$p = \rho \cdot h \cdot g$** **(equation 8)**

Question 9
The first drawing shows the gauge at rest. On the second drawing, pressure is applied. In this case, the height of the column of water is 30 cm.





Here is the calculation of the maximum water pressure measurable by this gauge:

(Data)	**(Equation)**	**(Calculation)**
$p = ?\ kPa$ $\rho = 1\ g/cm^3$ $h = 30\ cm$ $g = 9.8\ N/kg$	$p = \rho \cdot h \cdot g$	$p = 1\frac{g}{cm^3} \cdot 30cm \cdot 9{,}8\frac{N}{kg} \cdot \frac{1kg}{1000g} \cdot \frac{10000cm^2}{1m^2}$ $p = 2940\frac{N}{m^2}$ $p = 2940Pa \cdot \frac{1kPa}{1000Pa}$
		(Answer)
		(Maximum pressure) $p \approx 2{,}9kPa$

Draw your conclusions

Question 1

To measure a greater variation in pressure with this gauge, we need only increase the height of the tube. In this way, the force of gravity borne by the column of water would be greater.

Question 2

Yes, it is possible to measure a negative pressure (suction) with this liquid column gauge. You would, however need to lengthen the tube on the side where the suction is applied.

Question 3

Mercury has a greater density than water.

$\rho_{mercury} = 13.6\ g/cm^3$ $\rho_{water} = 1\ g/cm^3$

The force of gravity borne by the column of mercury is therefore greater. A mercury liquid column gauge can therefore measure a greater pressure without having to lengthen the glass tube.

Question 4

Real pressure = pressure of the gauge + atmospheric pressure

Real pressure = 3 kPa + 100 kPa = 103 kPa

Question 5

$$p = \rho \cdot h \cdot g$$

$$p = 1\frac{g}{cm^3} \cdot h(cm) \cdot 9,8\frac{N}{kg} \cdot \frac{1kg}{1000g} \cdot \frac{10000cm^2}{1m^2}$$

$$p(Pa) = 98 \cdot h(cm)$$

$$\boxed{p(kPa) = 0,098 \cdot h(cm)}$$

If we measure the height of the column of water only on one side, the equation becomes: p(kPa) = 0.196 • h(cm)

The effect of temperature on the pressure of a gas (Gay-Lussac's Law [2])

Questions: What is the effect of a variation in temperature (in K) on the volume of a gas (in kPa)? What kind of curve could we draw, experimentally? What mathematical relationship links these two physical sizes?

Prove experimentally and show mathematically.

Directed laboratory

Data table (example)		
No.	**Temperature of the air in the Erlenmeyer flask (°C)**	**Height of the column of coloured water (cm)**
1	*26*	*3.17*
2	*27*	*5.10*
3	*28*	*6.62*
4	*29*	*8.07*
5	*30*	*9.25*
6	*31*	*11.07*
Atmospheric pressure (kPa)	101.325	

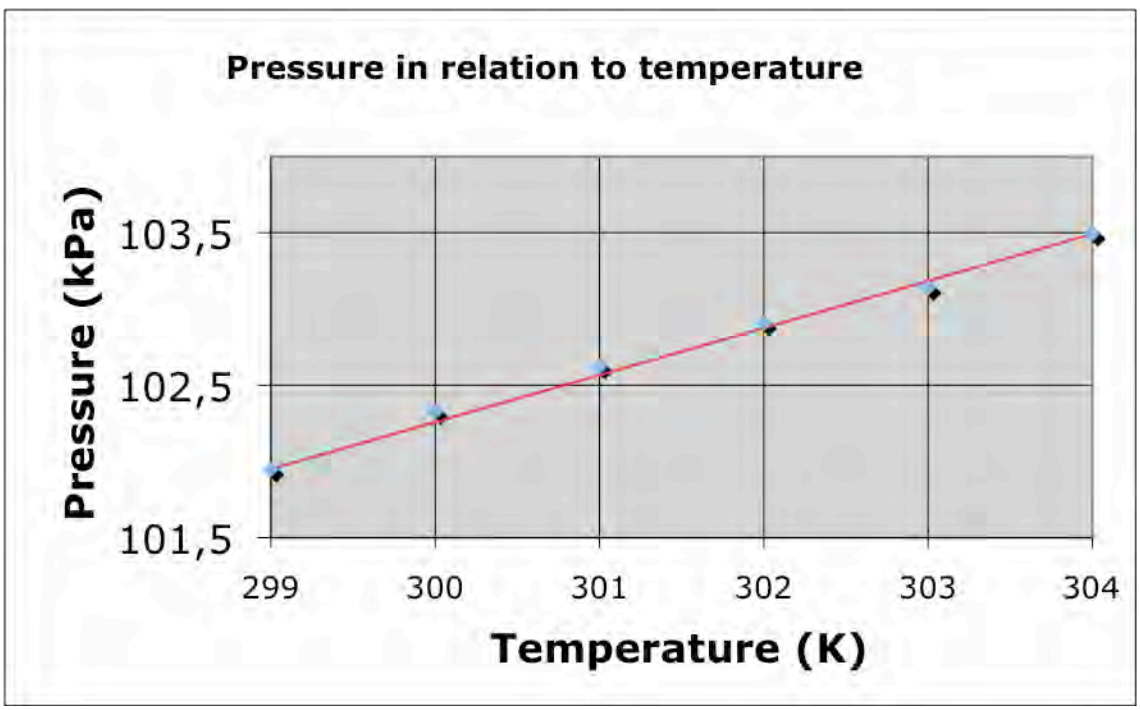
[2] In certain works, the laws of Charles and Gay-Lussac are not associated to the same relations linking volume, pressure and temperature. The historic contribution of each of these scientists does not seem to be recognized the same way by all authors.

Analyse the results (example)

Process your data

Question 1 See temperatures and pressures calculated in the table below.

No.	Temperature of the air (K)	Relative air pressure (kPa)	Absolute air pressure (kPa)
1	*299*	*0.621*	*101.946*
2	*300*	*1.000*	*102.325*
3	*301*	*1.298*	*102.623*
4	*302*	*1.582*	*102.907*
5	*303*	*1.813*	*103.138*
6	*304*	*2.170*	*103.495*



Emphasise the tendencies

Question 2
It is a linear mathematical equation.

Question 3
The rate of variation is: 0.3086 kPa/K (ordinal at the beginning: 9.69)

Draw your conclusions

Question 4

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Question 5
If p = 0 kPa, T = -31.4 K (This is an impossible value that nonetheless approaches ≈ 0 K)

Question 6 To zero degrees Kelvin (absolute zero).

Question 7

(Data)	(Equation)	(Calculation)
T_2 = ? K p_2 = 1034 kPa T_1 = 253 K p_1 = 931 kPa	$T_2 = p_2 \cdot T_1 / p_1$	T_2 = 1034 kPa · *253 K* / 931 kPa **(Answer)** T_2 = 281 K = 8 °C

Question 8

(Data)	(Equation)	(Calculation)
p_2 = ? mm Hg p_1 = 735 mm Hg T_2 = 304 K T_1 = 295 K	$p_2 = p_1 \cdot T_2 / T_1$	P_2 = 735 mm Hg · 304 K / 295 K **(Answer)** P_2 = 757 mm Hg

No, this pressure is still lower than atmospheric pressure. The two spheres will therefore stay together.

Question 9

(Data)	(Equation)	(Calculation)
p_2 = ? mm Hg p_1 = 760 mm Hg T_2 = 313 K T_1 = 310 K	$p_2 = p_1 \cdot T_2 / T_1$	P_2 = 760 mm Hg · 313 K / 310 K **(Answer)** P_2 = 767 mm Hg

Preparation of the material (Effect of temperature on the pressure of a gas)

Available material

- Safety glasses
- 1 glass cutter
- 1 Bunsen burner
- 1 ruler
- 1 - 60 cm. U shaped glass tube
- 1 - #5 rubber stopper with two holes
- 1 thermometer
- 1 – 5 cm. long glass tube 5 mm in diameter
- Un bit of glycerine
- 2 large head pins (minimum length 3.5 cm.)
- 2 small pieces rigid wire
- 1 - 12 volt (3 watt) light bulb
- 1 - 125 mL Erlenmeyer flask
- 1 Polystyrene glass
- 1 – 5 mm thick « foamcore » washer 8 cm in diameter
- Masking tape

N.B. It is possible to use a 9V battery, but it is more expensive, not ecological and less stable (decreasing tension).

<u>Method for preparing the glass tube</u>:

1. Measure a 60 cm. length of glass tubing
2. Cut the tube and using the flame of the burner, heat the glass to form a U.

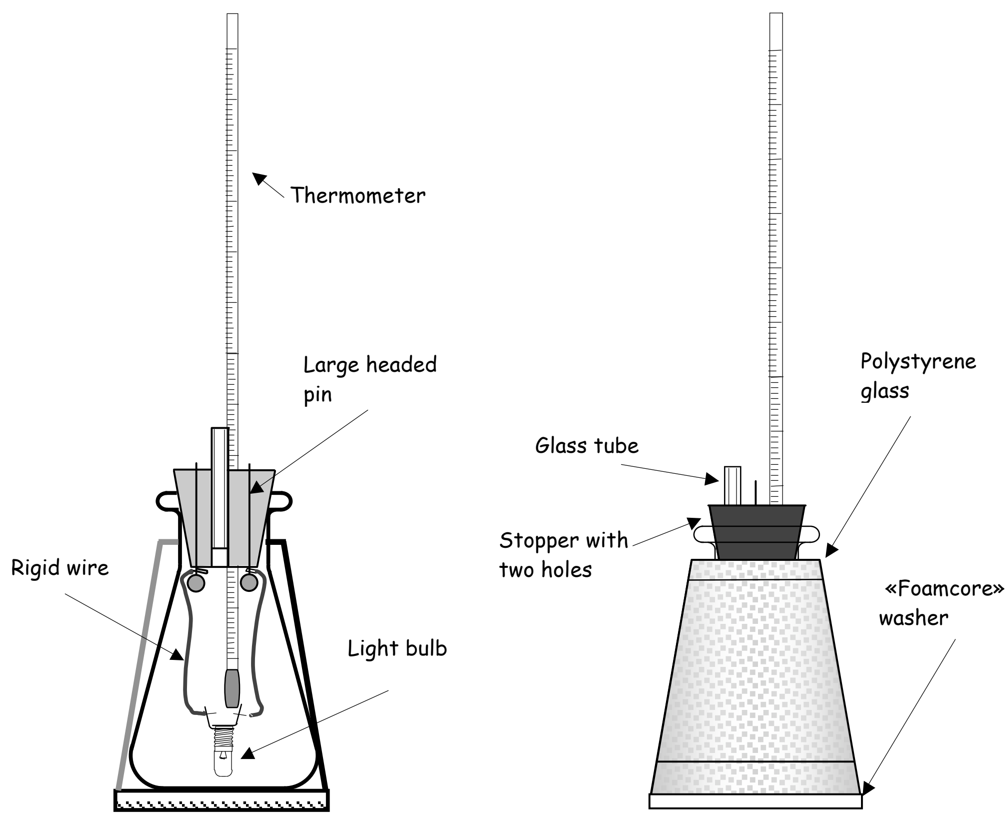
<u>Method for preparing the rubber stopper</u>:

1. Poke the two pins through the rubber stopper from the inside towards the outside of the Erlenmeyer flask. (See the assembly sketch).
2. Insert the thermometer in one of the holes of the rubber stopper so that it protrudes 7 cm. into the flask. (Put a little glycerin on the end of the thermometer to help it slide into the hole).

3. Insert the small glass tube into the other hole in the stopper (use glycerin to ease insertion and to avoid injury).
4. Connect the light bulb to the two interior extremities of the pins using rigid wire.

<u>Method for preparing the Polystyrene glass</u>:

1. Cut an opening into the bottom of the Polystyrene glass to be able to insert the neck of the Erlenmeyer flask.
2. Cut out a « foamcore » washer having the same diameter as the top opening of the glass.
3. Place the glass on the flask and attach the foamcore washer with masking tape to insulate the flask.



Questionnaire on the general law of gases

Question 1

Complete the synthesis table below:

Physical sizes	Equation
Effect of the variation of temperature on the volume of a gas	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Effect of the variation of pressure on the volume of a gas	$p_1 . V_1 = p_2 . V_2$
Effect of the variation of temperature on the pressure of a gas	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$

Question 2

(Data)	**(Equation)**	**(Calculation)**
p_2 = ? mm Hg p_1 = 760 mm Hg T_2 = 313 K T_1 = 310 K	$p_2 = \frac{p_1 . V_1 . T_2}{T_1 . V_2}$	$p_2 = \frac{101 \text{ kPa} . 4 \text{ L} . 275 \text{ K}}{293 \text{ K} . 7 \text{ L}}$
		(Answer)
		P_2 = 54 kPa

FOR THE TEACHING STAFF

Student's mandate

The students should:

Become comfortable with the concepts implicated in the function of the Stirling Engine. (D_c3)

The students must form teams of two people and meet to complete the learning activities.

Operate a small laboratory Stirling engine. (D_c2)

Adjust the Stirling engine in order to make it work correctly.

Analyse the function of the Stirling engine (D_c2)

Explain the global function of the engine using the scientific concepts studied.

Reflection on the Stirling engine (D_c3) (GFD)

Produce a reflexive text dealing with:

- its advantages and disadvantages, a comparison to internal combustion engines,
- a reflection as to its future, considering environmental concerns or on improvements to be made to it.

Analysis of the laboratory Stirling engine

The security capsule below may be distributed to students.

Security capsule

(11b) Candle




1. Be careful of burns! The flame may be invisible in daylight.
2. Tie long hair back and be careful of your sleeves in order to avoid them coming into contact with the flame and catching fire.
3. Wear safety glasses to protect yourself from projections.
4. Wear protective clothing against accidental projections. (Never direct the opening of a test tube towards yourself or anyone else.)
5. Use the appropriate tongs to manipulate the laboratory glassware (tongs for beakers, test tubes, etc.)
6. Take the time to think about each of your gestures.
7. Know where the safety equipment is and learn how to use it (fireproof blanket, fire extinguisher, eyewash, fire alarm, etc.)




Ensure that any modifications to this capsule do not compromise student safety.
Any person found to be at fault will have to assume their choices.

The role of each component

No.	Component	Role of the component
1	400 mL beaker	Enclose a given volume of gas. The transparency of the beaker allows us to see the displacer move.
2	Gas displacer	Displaces the gas from the heat source to the cold source and vice versa.
3	Cooling container	Cools the top of the beaker and in a lesser way, protects the mechanism from overheating.
4	Hot glue joint	Joins the beaker and the support plate and makes the system airtight in order to eliminate any gas leakage.
5	Support plate	Supports the entire mechanism. With the beaker, encloses a given volume of gas.
6	Flywheel	Increases the inertia of the engine. It allows the engine to continue rotating even when there is no force applied.
7	Adjustment screw and nut	Counter balance the mass of the displacer so that the speed of rotation is uniform throughout an entire rotation.
8	Crankshaft	Synchronises the displacer with the membrane drive in order to obtain great efficiency.
9	Displacement rod	Links the crankshaft, which is in rotation, to the displacer rod which only moves in translation.
10a	Displacer linkage tubes	Allows for the adjustment of the vertical position of the displacer and for a limited rotation of the displacement rod.
10b	Membrane linkage tubes	Allows for the adjustment of the vertical position of the membrane.
11	Line out of displacer	Links the displacer to the displacement rod.
12	Membrane rod	Links the crankshaft, which is in rotation, to the membrane displacer rod which moves mostly in translation
13	Line out of the membrane	Links the membrane to the membrane rod.
14	Membrane	Allows the pressure of the gas to generate labour (force and displacement).
15	Expansion chamber	Allows the membrane to be fastened to the rest of the system so that it is perfectly airtight
16	Heat source (candle)	Supplies the thermal energy (heat) necessary to the system's function

Your comic strip

For a complete description of this section, see the PowerPoint presentation called: Stirling_explanations_chemistry.

Integration and reinvestment

The webography below may help feed the student's thought process.

Reflection on the Stirling engine
Webography 1. Diesel and gas engines (principles, output, …)http://www.ifp.fr/espace-decouverte-mieux-comprendre-les-enjeux-energetiques/les-cles-pour-comprendre/automobile-et-carburants/les-moteurs-conventionnels 2. Stirling Engine (principles, output, …) http://en.wikipedia.org/wiki/Stirling_engine 3. Advantages and disadvantages of the Stirling engine http://www.moteurstirling.com/avanconvenient.php 4. Future applications for the Stirling engine http://www.moteurstirling.com/applications2.php 5. Current or past applications for the Stirling engine http://www.moteurstirling.com/applications1.php **For the teaching staff, a little thermodynamics (French).** 1. At this address, you will find a very interesting animation describing the Stirling cycle, theoretically. http://www.sciences.univ-nantes.fr/physique/perso/gtulloue/Thermo/Machines/Stirling2.html 2. Though this document in university level, note figure 7 on page 15. There you will see the theoretical cycle and the real cycle which is rather more rounded. http://auditoires-physique.epfl.ch/uploads//393/393.pdf