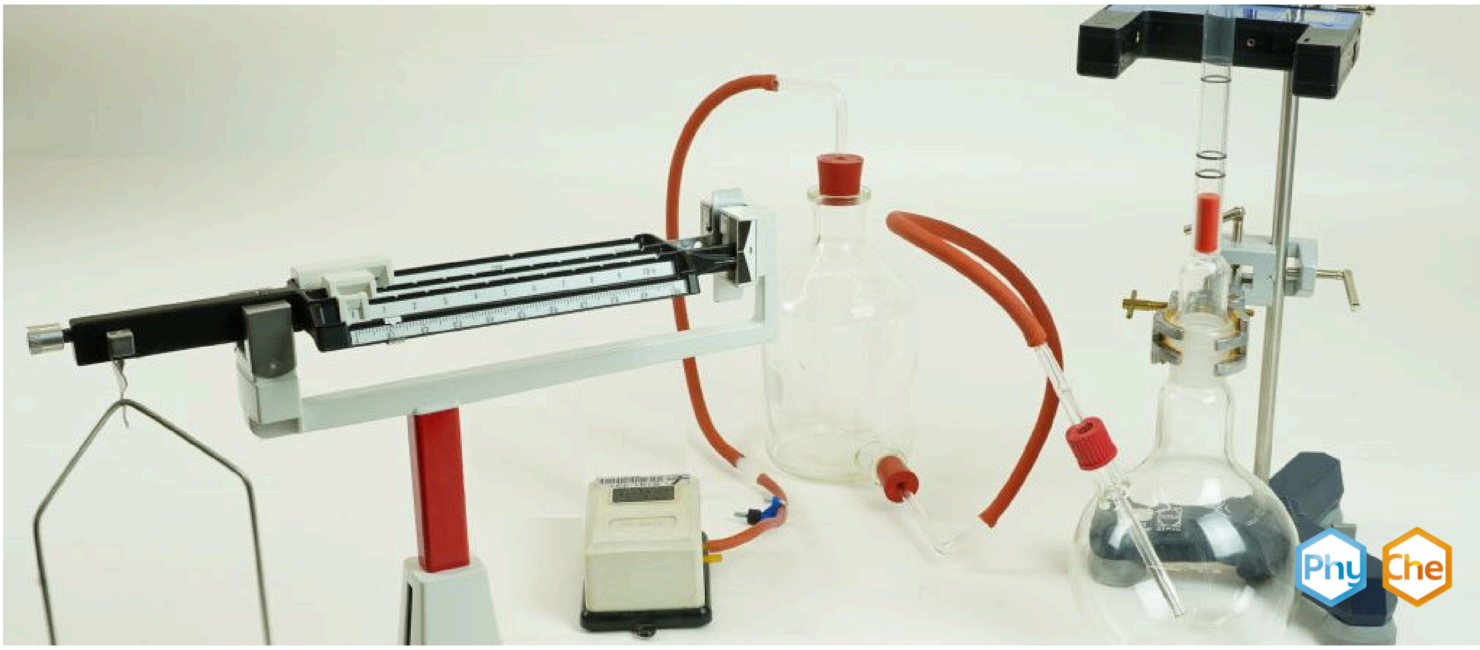
Adiabatic coefficient of gases - Flammersfeld oscillator



P2320502

Physics	Thermodynamics	Calorimetry
Chemistry	Physical chemistry	Thermochemistry, calorimetry

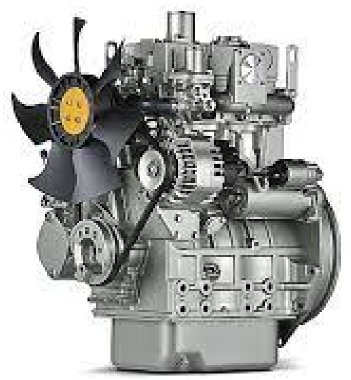
Difficulty level	Group size	Preparation time	Execution time
hard	-	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/673cba55b191020002144fe8

General information

Application



A diesel engine

The expansion and compression of adiabatic process can be found in heating and cooling equipments and machines.

- Adiabatic heating occurs when the pressure of a gas is increased by work done on it by its surroundings.
- Adiabatic cooling occurs when the pressure on an adiabatically isolated system is decreased, allowing it to expand, thus causing it to do work on its surroundings.

The technical applications of the process can be seen in diesel engine and gas turbines.

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Other information (1/2)

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Prior knowledge

First Law of thermodnamics explains the change in internal energy ΔU of a closed system is equal to the quantity of energy Q supplied to the system as heat minus the amount of thermodynamic work done W by the system on its surrounding.

$$\Delta U = Q - W$$

Scientific principle

A mass oscillates on a volume of gas in a precision glass tube. The oscillation is maintained by leading escaping gas back into the system. The adiabatic coefficient of various gases is determined from the periodic time of the oscillation.

Other information (2/2)

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Learning objective

Understanding the adiabatic process of a system by determining the adiabatic coefficient χ of gases.

Tasks

Determine the adiabatic coefficient χ of air, nitrogen and carbon dioxide (and also argon, if present) from the periodic time of oscillation T, the mass m, and the volume V of the gas.

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Safety instructions

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The general instructions for safe experimentation in science lessons apply to this experiment.

For the H and P phrases, please consult the safety data sheet of the respective chemical.

Carbon dioxide
H280 Contains pressurised gas; may explode if heated.
P403 Store in a well-ventilated place.

Nitrogen
H280 Contains pressurised gas; may explode if heated.
P403 Store in a well-ventilated place.

Theory (1/5)

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In order to maintain a stable, undamped oscillation, the gas escaping through the unavoidable gap between the precision glass tube and the oscillator is channelled back into the system via a tube. There is also a small opening in the centre of the glass tube. The oscillator can initially be located below this opening. The gas flowing back into the system causes a slight overpressure to build up, which pushes the oscillator upwards. As soon as the oscillator has left the opening, the overpressure escapes, the oscillator sinks and the process is repeated. In this way, the actual free oscillation is superimposed by a small, in-phase excitation.

If the body now swings from the equilibrium position by the small distance x then p Changes due to Δp and the expression for the occurring forces is

$$m \frac{d^2x}{dt^2} = \pi r^2 \Delta p \quad (1)$$

(m = Ground of the oscillator ; r = radius of the oscillator ; p = internal gas pressure)

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Theory (2/5)

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$$p = P_L + \frac{mg}{\pi r^2} \text{ (2)}$$

(g = Acceleration due to gravity ; P_L = external atmospheric pressure)

As the oscillating process takes place relatively quickly, we can consider it to be adiabatic and set up the adiabatic equation:

$$p \cdot V^{\chi} = const$$

V = volume of the gas.

The differentiation results in

$$\Delta p = \frac{p \chi \Delta V}{V} \text{ (3)}$$

Theory (3/5)

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Substitution of (2), with $\Delta V = \pi r^2 x$ in (1) gives the differential equation of the harmonic oscillator

$$\frac{d^2 x}{dt^2} + \frac{\chi \pi^2 r^4 p}{mV} x = 0 \text{ (3)}$$

for which the known solution for the angular velocity ω is:

$$\omega = \sqrt{\frac{\chi \pi^2 r^4 p}{mV}} x \text{ (4)}$$

The following applies to the period of the oscillation $T = \frac{2\pi}{\omega}$. It will be the time t for a large number of n of vibrations are measured and used to calculate the period time T used.

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Theory (4/5)

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Insert the period duration into (4) and transform to χ supplies:

$$\chi = \frac{4mV}{T^2 p r^4} \quad (5)$$

The adiabatic coefficient can be predicted from the kinetic theory of gases - regardless of the type of gas - solely from the number of degrees of freedom of the gas molecule. The number of degrees of freedom of the gas molecule depends on the number of atoms that make up the molecule. A monoatomic gas has only 3 translational degrees of freedom, a diatomic gas has an additional 2 rotational degrees of freedom, and triatomic gases have 3 rotational degrees of freedom and 3 translational degrees of freedom, i.e. a total of 6.

(The vibration degrees of freedom are neglected for the temperatures considered).

Theory (5/5)

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This means that the adiabatic coefficient is given by according to the kinetic theory of gases and independent of the type of gas:

$$\chi = \frac{f+2}{f}$$

For monoatomic gases: $f = 3$, $\chi = 1.67$

For diatomic gases: $f = 3$, $\chi = 1.40$

For triatomic gases: $f = 3$, $\chi = 1.33$

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Equipment

Position	Material	Item No.	Quantity
1	Gas oscillator, Flammersfeld	04368-00	1
2	Graduated cylinder, Borosilicate, 1000 ml	36632-00	1
3	Aspirator bottle,clear gl.1000ml	34175-00	1
4	Air control valve	37003-00	1
5	Cobra SMARTsense Dual Photogate - Double light barrier 0 ... ∞ s (Bluetooth + USB)	12945-00	1
6	Micrometer screw gauge 0 - 25 mm	03012-00	1
7	Glass tube,right-angled,.	MAU-10030703	1
8	Rubber stopper, d = 22/17 mm, 1 hole	39255-01	1
9	Rubber stopper 26/32, 1 hole 7 mm	39258-01	1
10	Rubber tubing, i.d. 6 mm	39282-00	2
11	Balance OHAUS LG 311, 4 beams, 0...311 g	44007-31	1
12	Aquarium pump, 150 l/h, 230 V AC	64566-93	1
13	Precision barometer, d=100mm	87998-00	1
14	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
15	Tripod base PHYWE	02002-55	1
16	Support rod, stainless steel, 500 mm	02032-00	1
17	Right angle clamp expert with fulcrum screw	02054-00	2
18	Universal clamp	37715-01	1
19	Reducing valve for CO2 / He	33481-00	1
20	Reducing valve f.nitrogen	33483-00	1
21	Steel cylinder,CO2, 10l, full	41761-00	1
22	Steel cylinder,nitrogen,10l, full	41763-00	1
23	Tubing adaptor, ID 3-5/6-10 mm	47517-01	1
24	Glass tubes,straight, 200 mm, 10	MAU-16074543	1
25	Rubber tubing, i.d. 3 mm	39279-00	1

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Setup and procedure

Structure (1/4)

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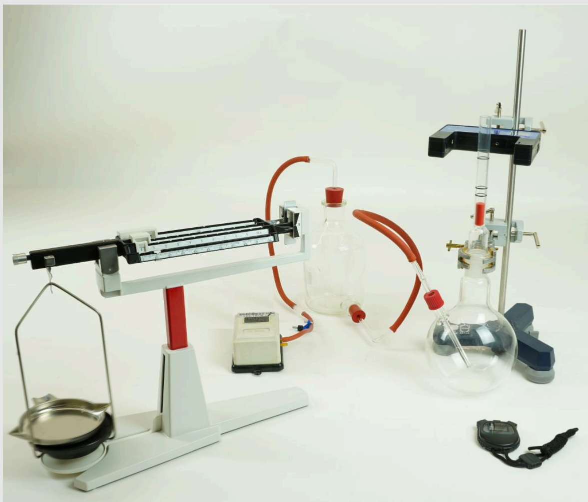

Experimental setup

The figure on the left shows the experimental setup. This consists of a gas oscillator (right), a SMARTsense Dual Photogate, another bottle connected to a pump. A running weight scale to determine the mass of the oscillator and a stopwatch to measure the time are also shown.

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Structure (2/4)

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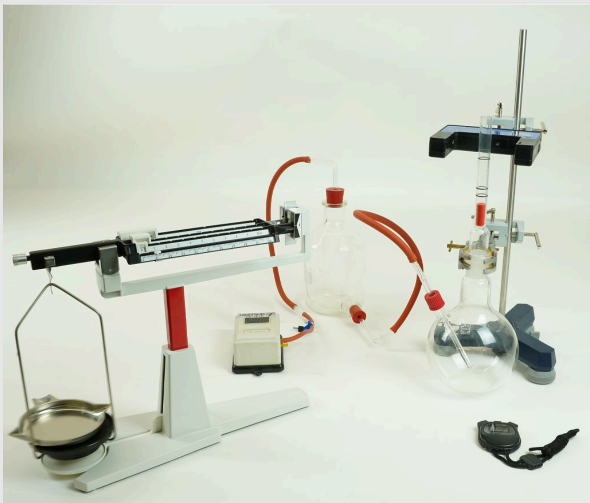

Experimental setup

The adiabatic coefficient can be determined with various gases.

Air
If air is to be used, the bottle (as a buffer) is used with the pump with which the required pressure can be generated.

Other gases
If other gases are used, e.g. carbon or nitrogen, these can be taken directly from the steel cylinder and fed into the gas oscillator via a pressure-reducing valve.

Structure (3/4)

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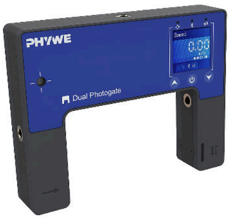
Gas oscillator

- Set up the tripod as shown in the illustration on the left and attach the Dual Photogate sensor to the rod using a right angle clamp.
- Clean the tube of the glass oscillator thoroughly with alcohol and insert the red oscillator carefully.
- Align the light beam of the Dual Photogate so that it passes through the centre of the tube.
- Switch on the Dual Photogate and select the mode COUNT with the arrows to count the number of oscillations of the oscillator.



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Structure (4/4)

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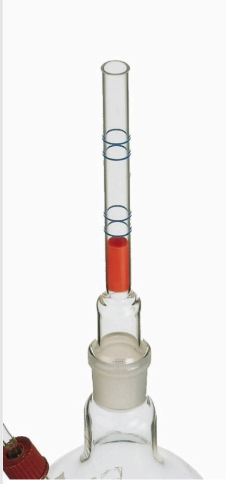

Gas oscillator

Measurement with carbon or nitrogen

- Use the reducing valve on the steel cylinder and the fine adjustment valve on the intake to adjust the gas flow rate so that the oscillator swings symmetrically around the gap. The blue rings serve as a guide.
- If the centre of gravity of the oscillation is clearly above the gap and the oscillation stops because the gas pressure is slightly reduced, clean the glass tube again (accumulation of dust in the system).
- If you carry out the experiment with air, you must set the pump so that the oscillator oscillates stably.

Notes

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- The movement of the plastic body in the glass tube can generate static charges that distort the measured values. This effect can be avoided by applying a thin layer of graphite to the oscillator. The easiest way to do this is to rub the oscillator with the lead of a soft pencil. It may also be advantageous to treat the glass tube with an antistatic agent, e.g. a 3% calcium chloride solution.
- Important: The oscillator is a precision part and must be handled with care. Only insert the oscillator into the tube after switching on the glass flow and place your hand lightly over the opening of the tube until a constant amplitude is achieved so that the oscillator is not ejected. If the oscillator becomes wedged at the lower end of the tube, remove the glass tube and carefully loosen the oscillator with the blunt end of a pencil.
- It is advisable to measure different gases in order of their specific gravity to ensure that any lighter gas is completely displaced from the volume.

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Procedure (1/2)

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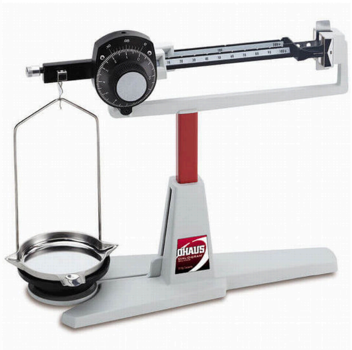

Determination of the mass

- Measure the ambient pressure P_L with the precision barometer.
- Measure the mass m of the oscillator using the running weight scale.
- Measure the diameter $2r$ of the oscillator carefully with a micrometre screw gauge.

If necessary, take the average value from several measurements at different positions, as the result depends to a large extent on the accuracy of this measurement.

Procedure (2/2)

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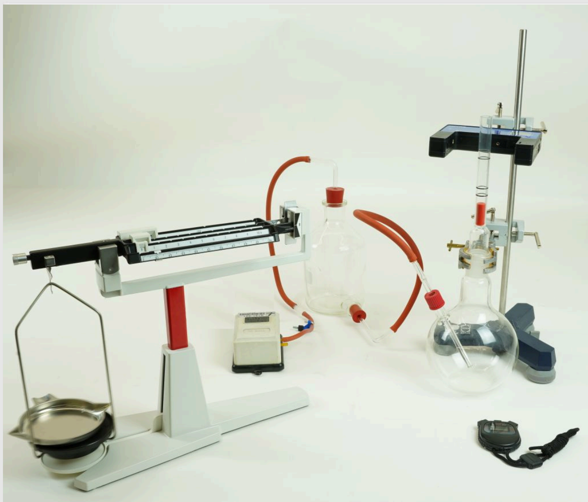

Experimental setup

Determine the volume V of the gas at the end of the experiment by weighing it:

- Firstly, the glass flask with the empty precision tube is weighed.
- It is then filled with water up to the slot and weighed again.
- Determine the volume from the density of the water (depending on the water temperature).

Alternatively, the volume can also be determined by emptying the water into a measuring cylinder.

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Evaluation (1/2)

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Results of the mass determination m of the volume V the ambient pressure P_L and the radius r:

$m = 4.59 \cdot 10^{-3}\ kg$

$V = 1.14 \cdot 10^{-3} m^3$

$P_L = 99.56 \cdot 10^3\ \frac{kg}{ms^2}$

$r = 5.95 \cdot 10^{-3}\ m$

Ten measurements, each with about n = 300 oscillations, resulted for the adiabatic coefficients

Nitrogen $\chi = 1.39 \pm 0.07$

Carbon dioxide $\chi = 1.28 \pm 0.08$

Air $\chi = 1.38 \pm 0.08$

(Argon $\chi = 1.62 \pm 0.09$)

Evaluation (2/2)

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The adiabatic process can be explained as follows:

- [ ] a process in which no heat enters or leaves a system.
- [ ] the system is isolated from the environment.
- [ ] the pressure remains constant.

See

Fill in the missing words

Adiabatic constant χ for a gas depends on the effective number of ________ in the molecular motion.

See

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Slide	Result/In Total
Slide 21: Multiple tasks	**0/3**

Total score 0/3

Show solutions Repetition

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