Adiabatic coefficient of gases - Flammersfeld oscillator

P2320500

Physics	Thermodynamics	Temperature & Heat
Physics	Thermodynamics	Heat energy, thermal capacity
Physics	Thermodynamics	Conversion of heat, entropy
Chemistry	Physical chemistry	Thermochemistry, calorimetry

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

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General information

Application

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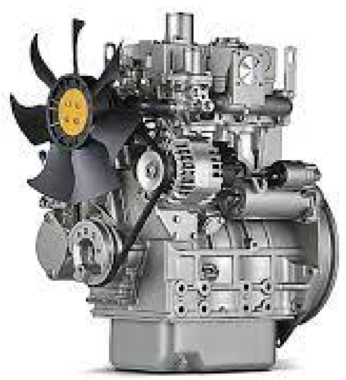

A diesel engine

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)

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)

Learning objective

Understanding 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 of argon, if available) from the periodic time of the oscillation T of the mass m on the volume V of gas.

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Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

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

Carbon dioxide
H280: Contains gas under pressure; may explode if heated.
P403: Store in a well ventilated place.

Nitrogen
H280: Contains gas under pressure; may explode if heated.
P403: Store in a well ventilated place.

Theory (1/5)

In order to maintain a stable, undamped oscillation, the gas escaping through the inevitable clearance between the precision glass tube and the oscillator is led back to the system via a tube. Secondly, there is a small opening in the centre of the glass tube. The oscillator may initially be located below the opening. The gas flowing back into the system now causes a slight excess pressure to build up and this forces the oscillator upwards. As soon as the oscillator has cleared the opening, the excess pressure escapes, the oscillator drops and the process is repeated. In this way, the actual free oscillation is superimposed by a small, inphase excitation.

If the body now swings out of the equilibrium position by the small distance x, then p changes by δp , and the expression for the forces which occur is:

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

m = mass of the oscillator ; r = radius of the oscillator ; p = internal gas pressure;

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Theory (2/5)

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

g = acceleration due to gravity ; P_L = external atmospheric pressure

Since the oscillatory process takes place relatively quickly, we can regard it as being adiabatic and set up the adiabatic equation:

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

V = volume of gas.

Differentiation gives

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

Theory (3/5)

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

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

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

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

Further, the periodic time of the oscillation,

$$T = \frac{2\pi}{\omega}$$

(Time t for a large number n of oscillations is measured (stop watch) and used to calculate period time T).

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Theory (4/5)

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Hence

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

The adiabatic coefficient can be predicted from the kinetic theory of gases – irrespective 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 is dependent upon the number of atoms from which the molecule is composed. A monatomic gas has only 3 degrees of translation, a diatomic gas has an additional 2 degrees of rotation, and triatomic gases have 3 degrees of rotational freedom and 3 of translational freedom, making 6 in all.

(The vibrational degrees of freedom are disregarded at the temperatures under consideration).

Theory (5/5)

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This means that from the kinetic theory of gases, and irrespective of the type of gas, the adiabatic coefficient is given by:

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

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	Light barrier with counter	11207-30	1
6	Power supply 5 V DC/2.4 A with 4 mm plugs	11077-99	1
7	Micrometer screw gauge 0 - 25 mm	03012-00	1
8	Glass tube,right-angled, 10 pcs.	36701-52	1
9	Rubber stopper, d = 22/17 mm, 1 hole	39255-01	1
10	Rubber stopper 26/32, 1 hole 7 mm	39258-01	1
11	Rubber tubing, i.d. 6 mm	39282-00	2
12	Balance OHAUS LG 311, 4 beams, 0...311 g	44007-31	1
13	Aquarium pump, 150 l/h, 230 V AC	64566-93	1
14	Precision barometer, d=100mm	87998-00	1
15	Stop watch, interruption type	03076-01	1
16	Tripod base PHYWE	02002-55	1
17	Support rod, stainless steel, 500 mm	02032-00	1
18	Right angle clamp expert	02054-00	2
19	Universal clamp	37715-01	1
20	Reducing valve for CO2 / He	33481-00	1
21	Reducing valve f.nitrogen	33483-00	1
22	Steel cylinder,CO2, 10l, full	41761-00	1
23	Steel cylinder,nitrogen,10l, full	41763-00	1
24	Tubing adaptor, ID 3-5/6-10 mm	47517-01	1
25	Glass tubes,straight, 200 mm, 10	36701-66	1
26	Rubber tubing, i.d. 3 mm	39279-00	1

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Setup and procedure

Setup (1/3)

Experimental set-up

If the experiment is to be performed with air, then the required pressure is generated with a small pump. Place an aspirator bottle between the gas oscillator and the pump to act as a buffer, and insert a glass tube filled with cotton wool into the supply tube to the oscillator to trap any moisture.

If other gases are used for the experiment, then these can be taken directly from the steel cylinder and passed via a reducing valve (with a fine range of adjustment) into the gas oscillator. Clean the precision glass tube thoroughly (dust-free) with alcohol, set it up vertically, and insert the oscillator.

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Setup (2/3)

Align the beam of light from the light barrier so that it passed through the centre of the tube. The trigger threshold of the light barrier is set automatically after switch-on by pressing the RESET button. Select the operating mode COUNT in order to determine the number n of oscillations of the oscillator.

With the reducing valve on the steel cylinder and the fine control valve on the aspirator, set the flow rate of the gas so that the oscillator oscillates symmetrically about the slit. The blue rings serve as a guide for this purpose. If the centre of oscillation clearly lies over the slit, and if the oscillation ceases when the gas pressure is reduced slightly, then dust has evidently found its way into the system and the glass tube must be cleaned again.

The motion of the plastic body in the glass tube can produce static charges which distort the readings. This effect can be avoided by applying a thin coating of graphite to the oscillator. The simplest way of doing 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, such as a 3% solution of calcium chloride.

Setup (3/3)

Important: The oscillator is a precision part and must be treated with care accordingly. Insert the oscillator into the tube only after the glas flow has been switched on, and place the hand lightly over the opening of the tube until a constant amplitude has been attained, in order to prevent the oscillator from being ejected. If the oscillator becomes wedged on 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 a series of gases in order of their specific gravities to ensure that each lighter gas is expelled completely from the volume.

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Procedure

Measure the mass m of the oscillator by weighing. Measure the diameter $2r$ of the oscillator carefully with a micrometer gauge using the ratchet. If necessary, take the mean value from several measurements at different positions, since the result depends to a considerable extent on the accuracy of this reading.

The volume of the gas is determined on completion of the experiment by weighing: first weigh the glass flask with precision tube empty, then fill it with water up to the slit and weigh it again.

Determine the volume from the density of water (dependent on the water temperature). The volume can also be determined by emptying the water into a graduated measuring cylinder.

Evaluation (1/2)

With values:

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

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

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

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

Ten measurements, each of about n = 300 oscillations, gave for the adiabatic coefficients

Argon $\chi = 1.62 \pm 0.09$

Nitrogen $\chi = 1.39 \pm 0.07$

Carbon dioxide $\chi = 1.28 \pm 0.08$

Air $\chi = 1.38 \pm 0.08$

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Evaluation (2/2)

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Adiabatic process can be explained by:

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

Check

Fill in the missing words

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

Check

Slide	Score / Total
Slide 18: Multiple tasks	0/3

Total Score 0/3

Show solutions   Retry

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