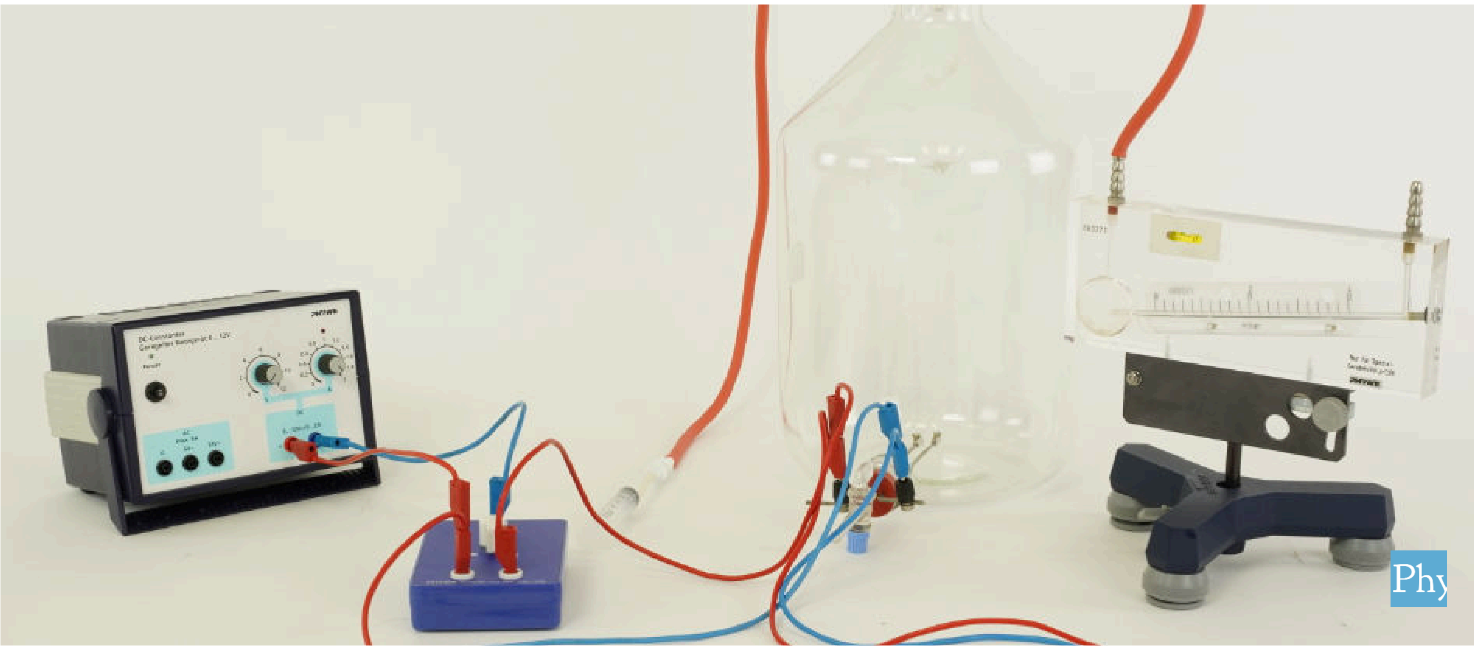
Heat capacity of gases with Cobra SMARTsense



P2320267

Physics	Thermodynamics	Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

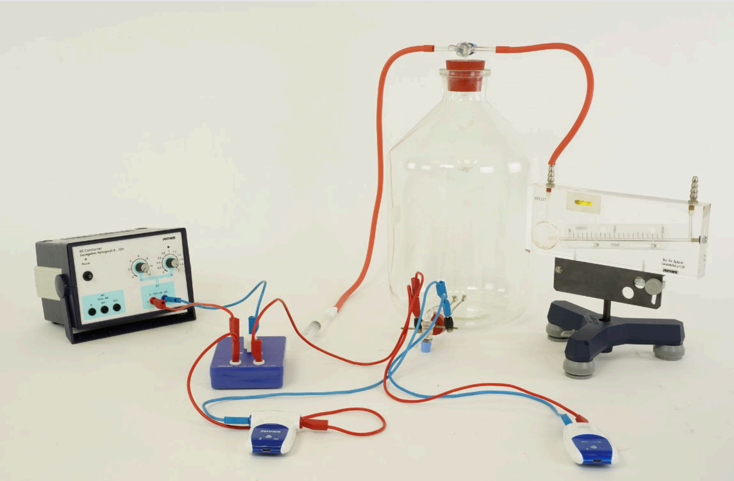
Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

General information

Application



Experiment for heat capacity of gases

Specific heat capacity of gases is important in technical applications that employ gases, such as heating or cooling process.

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE excellence in science

Prior knowledge

Prior knowledge is explained in theory section

Scientific principle

Heat is added to a gas in a glass vessel by an electric heater which is switched on briefly. The temperature increase results in a pressure increase, which is measured with a manometer. Under isobaric conditions a temperature increase results in a volume dilatation, which can be read from a syringe. The molar heat capacities C_V and C_p are calculated from the pressure and volume change respectively.

Other information (2/2)

PHYWE excellence in science

Learning objective

Understanding the application of specific heat capacity C_p and C_V

Tasks

1. Determine the molar heat capacities of air at constant volume C_V .
2. Determine the molar heat capacities of air at constant pressure C_p .

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

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.

Theory (1/10)

The first law of thermodynamics can be illustrated particularly well with an ideal gas. This law describes the relationship between the change in internal energy dU_i the heat exchanged with the surroundings dQ and the work performed by the system generally speaking. In our case the work being performed is the pressure-volume work results into a volume increase dV keeping constant the pressure p.

$$dQ = dU_i + p\,dV \qquad (1)$$

The molar heat capacity C of a substance results from the amount of absorbed heat dQ and the temperature change dT per mole where n is the number of moles:

$$C = \frac{1}{n} \cdot \left(\frac{dQ}{dT}\right) \qquad (2)$$

One distinguishes between the molar heat capacity at constant volume C_V and the molar heat capacity at constant pressure C_p .

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory (2/10)

PHYWE excellence in science

According to equations (1) and (2) and under isochoric conditions (V = const , $dV = 0$), the following holds true:

$$C_V = \frac{1}{n} \cdot \left(\frac{dU_i}{dT}\right) \qquad (3)$$

Under isobaric conditions (p = const , $dp = 0$):

$$C_p = \frac{1}{n} \cdot \left(\frac{dU_1}{dT} + p\frac{dV}{dT}\right) \qquad (4)$$

It is obvious form equation (3) that the molar heat capacity C_V is a function of the internal energy of the gas.

Theory (3/10)

PHYWE excellence in science

The internal energy can be calculated with the aid of the kinetic gas theory with the number of degrees of freedom f and the universal gas constant R :

$$U_i = \frac{1}{2} f \cdot R \cdot T \dot{n} \qquad (5)$$

Taking equation (3) into consideration it follows that:

$$C_V = \frac{f}{n} R \qquad (6)$$

Differentiating the equation of state for ideal gases

$$pV = nRT \qquad (7)$$

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory (4/10)

PHYWE excellence in science

gives the following for constant pressure:

$$p\frac{dV}{dT} = n \cdot R \qquad (8)$$

From relation (4) we obtain

$$C_p = \frac{f+2}{2} R \qquad (9)$$

With relations (6) and (9) follows that the difference between C_p and C_V for ideal gases is equal to the universal gas constant R .

$$C_p - C_V = R \qquad (10)$$

Theory (5/10)

PHYWE excellence in science

The number of degrees of freedom of a molecule is a function of its structure. All particles have three degrees of translational freedom. Diatomic molecules have an additional two degrees of rotational freedom around the principal axes of inertia. Triatomic molecules have three degrees of rotational freedom. Air consist primarily of oxygen (approximately 20 %) and nitrogen (circa 80 %), As a first approximation, the following can be assumed to be true for air:

$$f = 5$$

$$C_V = 2.5\,R$$

$$C_V = 20.8\,J \cdot K^{-1} \cdot mol^{-1}$$

and

$$C_p = 3.5\,R$$

$$C_p = 29.1\,J \cdot K^{-1} \cdot mol^{-1}$$

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory (6/10)

Task 1: Determine the molar heat capacities of air at constant volume C_V .

Under isochoric conditions, the temperature increase d_T produces a pressure increase d_p . The pressure measurement results in a minute alteration of the volume which must be taken into consideration in the calculation:

$$d_T = \frac{p}{nR} dV + \frac{V}{nR} dp = \frac{T}{pV}(pdV + Vdp) \qquad (11)$$

It follows from equations (3) and (1) that:

$$C_V = \frac{1}{n} \cdot \frac{dQ - pdV}{dT} \qquad (12)$$

Theory (7/10)

The energy dQ is supplied to the gas by the electrical heater:

$$d_Q \quad = U \cdot I \cdot dt \qquad (13)$$

There U is the voltage which is applied to the heater wires, I is the current which flows through the heater wires and dt is the period of time of the measurement.

With equations (11) and (13) one obtains:

$$C = \frac{p \cdot V}{n \cdot T} \cdot \frac{U \cdot I \cdot dt - p \cdot dV}{p \cdot dV + V \cdot dp} \qquad (14)$$

where dV is the volume change due to the rising oil in the manometer.

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory (8/10)

PHYWE excellence in science

The indicator tube in the manometer has a radius of r =2 mm and a length of l = 140 mm. The pressure change per length is accordingly $1/70\, hPa \cdot mm^{-1}$ and the corresponding change in volume is therefore:

$$d_V \quad = a \cdot dp \qquad (15)$$

where

$$a = \pi r^2 \cdot 70 \cdot \frac{mm}{hPa} = 881 \cdot 10^{-4} \frac{1}{hPa} \qquad (16)$$

thus

$$C_V = \frac{pV \cdot (dQ - a \cdot p \cdot dp)}{nT \cdot (a \cdot p + V)} \cdot dp \qquad (17)$$

Theory (9/10)

PHYWE excellence in science

The molar volume of a gas at standard pressure $p_0 = 1013\, hPa$ and $T_0 = 273.2\, K$ is $V_0 = 22.414\, mol^{-1}$. The molar volume is:

$$V_{mol} = \frac{p_0 \cdot V_0 \cdot T}{T_0 \cdot p} \qquad (18)$$

In accordance with the following, the number of moles in volume V is:

$$n = \frac{V}{V_{mol}} \qquad (19)$$

Taking equations (18) and (19) into consideration, it follows that:

$$C_V = \frac{p_0 \cdot V_0}{T_0} \cdot \left(\frac{dQ}{(ap+V) \cdot dp} - \frac{ap}{ap+V} \right) \qquad (20)$$

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory (10/10)

PHYWE excellence in science

Task 2: Determine the molar heat capacities of air at constant pressure C_p *.*

At constant pressure the temperature increase dT induces a volume increase dV . From the equation of state for ideal gases follows that:

$$dV = \frac{nR}{p}\, dt = \frac{V}{T}\, dT \qquad (22)$$

Taking equation (2) into consideration, the following results from equation (22):

$$C_p = \frac{1}{n} \cdot \frac{dQ \cdot V}{dV \cdot T} \qquad (23)$$

C_p can be calculated using equation (23) under consideration of (18) and (19):

$$C_p = \frac{p_0 \cdot V_0}{T_0} \cdot \frac{1}{p} \cdot \frac{dQ}{dV} \qquad (24)$$

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense - Voltage, ± 30 V (Bluetooth + USB)	12901-01	1
2	Cobra SMARTsense - Current, ± 1 A (Bluetooth + USB)	12902-01	1
3	measureLAB, multi-user license	14580-61	1
4	Precision manometer	03091-00	1
5	Weather monitor, 6 lines LCD	87997-10	1
6	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
7	Mariotte flask, 10 l	02629-00	1
8	Syringe 10ml, Luer, 100 pcs	02590-10	1
9	Stopcock,1-way,straight, glass	36705-00	1
10	Stopcock,3-way,t-sh.,capil.,glass	36732-00	1
11	Rubber stopper 26/32, 3 holes, 1 x 7 mm + 2 x 1,5 mm	39258-14	1
12	Rub.stop.d=59.5/50.5mm, 1 hole	39268-01	1
13	Rubber tubing, i.d. 6 mm	39282-00	2
14	Silicone tubing, inner diameter 3 mm	39292-00	1
15	Tubing adaptor, ID 3-5/6-10 mm	47517-01	1
16	Nickel electrode,d 3mm,w.socket	45231-00	2
17	Chrome-nickel wire, d.0,1mm,100m	06109-00	1
18	Scissors,straight,blunt,l 140mm	64625-00	1
19	On/off switch	06004-00	1
20	Connecting cord, 32 A, 500 mm, red	07361-01	2
21	Connecting cord, 32 A, 250 mm, blue	07360-04	1
22	Connecting cord, 32 A, 500 mm, blue	07361-04	2
23	Tripod base PHYWE	02002-55	1

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Additional equipment

PHYWE excellence in science

Position	Material	Quantity
1	PC	1

PHYWE excellence in science

Setup and procedure

PHYWE excellence in science

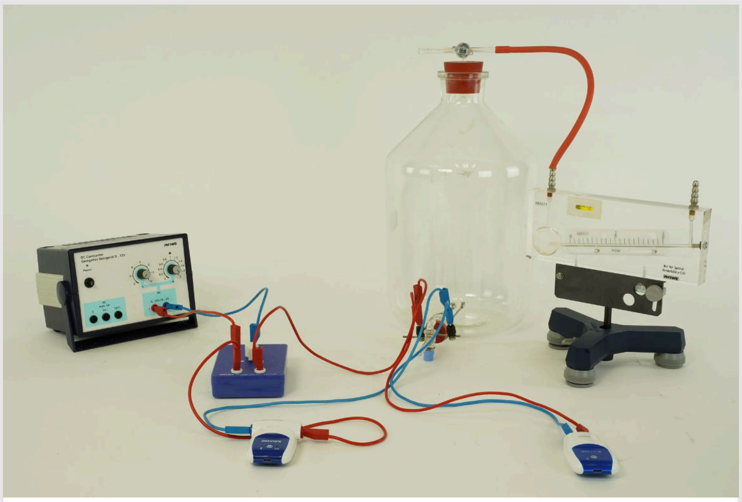
Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Setup (1/4)

PHYWE excellence in science



Experimental set-up for the determination of C_V

- Insert the two nickel electrodes into two holes of the three hole rubber stopper and fix the terminal screws to the lower ends of the electrodes.
- Screw two pieces of chrome nickel wire, which are each about 15 cm long, into the clamps between these two electrodes so that they are electrically connected in parallel. The wires must not touch each other.

Setup (2/4)

PHYWE excellence in science

- Insert the one-way stopcock into the third hole of the stopper and insert the thus prepared stopper in the lower opening of the bottle. Give special attention to the wires which have to protrude into the middle of the bottle.
- Insert the second stopper, which has been equipped with the three-way stopcock, into the upper opening of the bottle and connect the precision manometer to the bottle with a piece of tubing.
- The manometer must be positioned exactly horizontally.
- It is equipped with a spirit level to facilitate the correct adjustment. Use the adjusting screws of the tripod base to align the manometer completely horizontally.

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

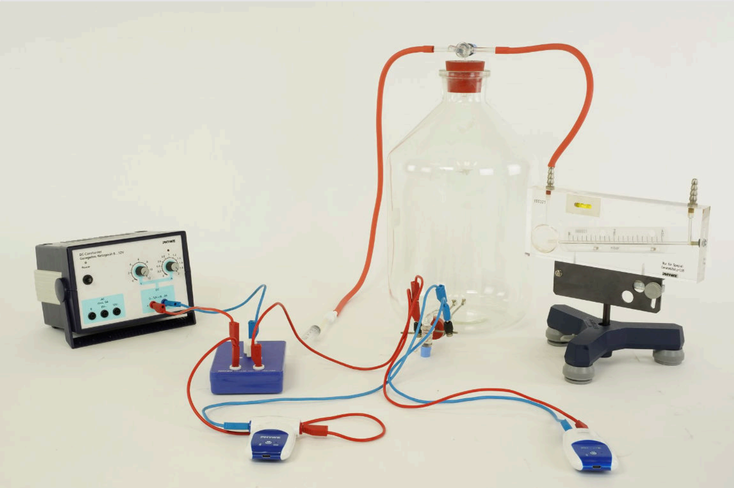
Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Setup (3/4)

- The manometer must be filled with the oil which is supplied with the device.
- The scale is now calibrated in hPa.
- You can choose the scale of either 2 hPa or 4 hPa by altering the inclination angle of the manometer. For these measurements 2 hPa are sufficient so just leave it horizontal.
- Combine the Cobra4 Sensor Unit Energy with the Cobra4 USB Link. Connect the power supply and the nickel electrodes with the current and voltage .
- Start the PC and connect the SMARTsense sensors with the computer via a USB cable.
- Call up the “Measure” programme and boot the experiment (experiment > open experiment). The measurement parameters for this experiment are loaded now.

Setup (4/4)



Experimental set-up for the determination of C_p

- To determine C_p connect the syringe to the bottle via the tree-way stopcock .
- For each task perform at least ten measurements.
- The rise tube of the manometer must be well wetted before each measurement.
- Determine the air pressure, which is required for the calculations, with the aid of the weather station.

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure (1/5)

PHYWE excellence in science

Task 1:

- Start and stop the measuring procedure by operating the two-way switch.
- The measuring procedure should be as short as possible (less than two seconds).
- The three-way cock must be positioned in such a manner, that it connects the bottle with the precision manometer.
- Upon heating the pressure in the bottle will start to rise.
- Read the maximum pressure increase immediately after cessation of the heating process.

Procedure (2/5)

PHYWE excellence in science

- After each measurement wait a sufficient time until the gas in the volume cooled down again to room temperature thereby regaining ambient pressure.
- The electrical current which flows during the measurements must not be too strong, i.e. it must be sufficiently weak to limit the pressure increase due to the heating of the gas to a maximum of 1 hPa.
- For this reason it may be necessary to use only one heating wire or to reduce the electrical current at the power supply.
- Stop the measurement.
- Send all data to „measure“ and save the measurement (File > Save meausrement as…).

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure (3/5)

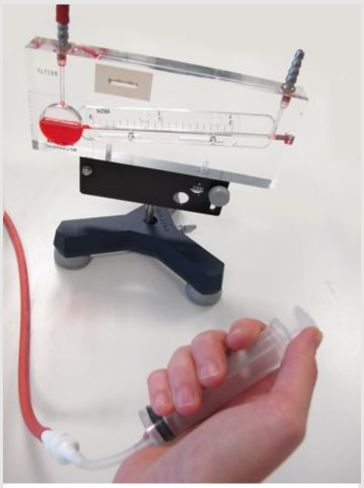
PHYWE excellence in science

Task 2:

- Start and stop the measuring procedure by operating the two-way switch.
- The measuring procedure should be as short as possible (less than two seconds).
- While measuring, the three-way cock must be positioned in such a manner that it connects the syringe and the manometer with the bottle.
- Upon heating the pressure in the bottle will start to rise.
- As you want to determine the heat capacity at constant pressure you have to compensate the pressure rise by increasing the volume via the syringe.

Procedure (4/5)

PHYWE excellence in science



Syringe

- You can hold the syringe in your hand and use your thumb to gently push the plunger.
- Operate the syringe with one hand while operating the switch with the other hand.
- When the heating stopped, the volume of the gas in the bottle will still increase for a moment.
- Be careful to notice the turning point when the volume starts decreasing again because the gas starts cooling down. In this moment the pressure should have its initial value and start falling while you have already stopped increasing the volume.

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

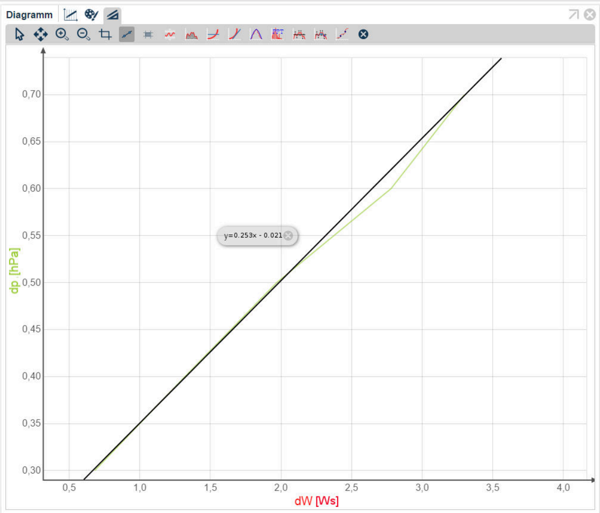
Procedure (5/5)

PHYWE excellence in science

- You can read the volume increase directly from the syringe's scale. You may need some practice until you are able to keep the pressure fairly constant during the whole measurement and recognize the turning point correctly.
- After each measurement reset the initial volume and wait until the gas cooled down again to room temperature.
- Before starting a new measurement both the volume in the syringe and the pressure should have regained their initial values.

Evaluation (1/4)

PHYWE excellence in science



Pressure change dp as a function of the heat supply dQ.

Task 1: Determine the molar heat capacities of air at constant volume C_V .

The slope of the linear regression in the figure is equal to:

$$\frac{dp}{dQ} = 0.253\,\frac{hPa}{VAs}$$

C_V can be calculated using equation (20) if equation (16) is taken into consideration. With p = 1011 hPa and V = 10 l :

$$C_V = 21.67\,J \cdot K^{-1} \cdot mol^{-1} \pm 5\,\%$$

PHYWE excellence in science

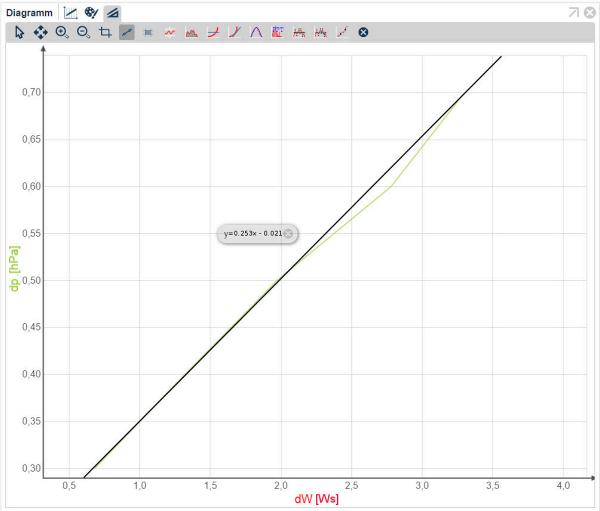
Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Evaluation (2/4)

PHYWE excellence in science



Pressure change dp as a function of the heat supply dQ.

Task 2: Determine the molar heat capacities of air at constant pressure C_p *.*

The slope of the linear regression in the figure is equal to:

$$\frac{dV}{dT} = 2.65 \, \frac{ml}{V\,As}$$

From which follows

$$C_p = 30.98 \, J \cdot K^{-1} \cdot mol^{-1} \, \pm \, 7\,\%$$

Evaluation (3/4)

PHYWE excellence in science

As a consequence of heat losses to the surroundings the experimental values for C_p and C_V are somewhat larger than the theoretical values.

The difference between the molar heat capacities provides the value for R . The experimental results give

$$R = C_p - C_V = 9.31 \, J \cdot K^{-1} \cdot mol^{-1} \, \pm \, 9\,\%$$

Which is congruent to the value given in the literature of $R = 8.3 \, J \cdot K^{-1} \cdot mol^{-1}$

Experimental results:

$$C_p(air) = 31 \, J \cdot K^{-1} \cdot mol^{-1}$$

$$C_V(air) = 22 \, J \cdot K^{-1} \cdot mol^{-1}$$

PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Evaluation (4/4)

PHYWE excellence in science

Fill in the blanks:

If the same amount of heat is supplied to the gas, molar heat capacities at constant ______ is greater than the molar heat capacities at constant ______ because energy is utilised to increase the ______ of the gas and expand the gas. No ______ is done by the gas at constant volume.

pressure Cp

temperature

work

volume Cv

Check

Slide	Score / Total
Slide 31: Summary of the experiment	0/4

Total Score 0/4

Show solutions Retry

PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de