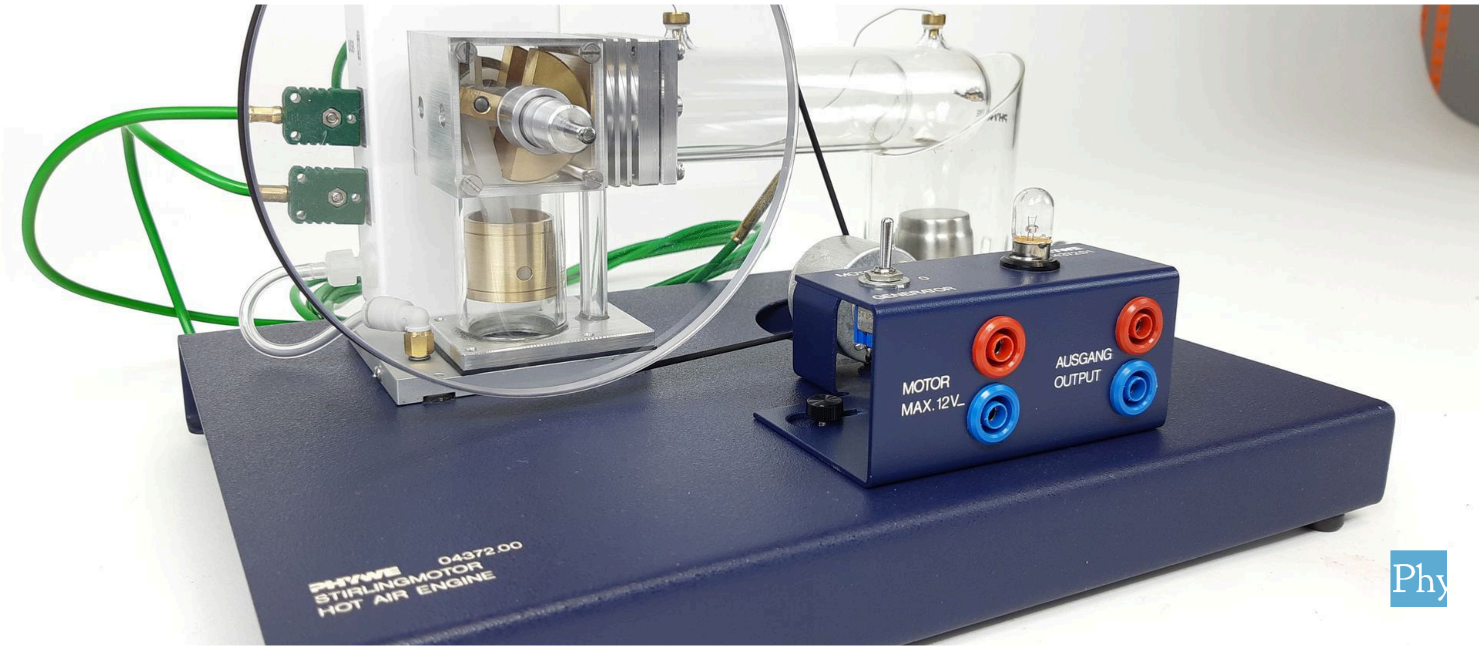
Stirling engine with measureLAB



Physics → Thermodynamics → Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	20 minutes

General information

Application

PHYWE Stirling engine transparent 04372-00

PHYWE's transparent Stirling engine combines the following features:

- Completely transparent - all important parts are visible
- Measurement of all experimental data through USB SmartSense module
- measureLAB compatible
- Large transparent flywheel.
- Both cylinder and displacement piston made of heatproof glass.
- Displacement piston with 2 measuring connecting pieces for temperature measurements.

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Application

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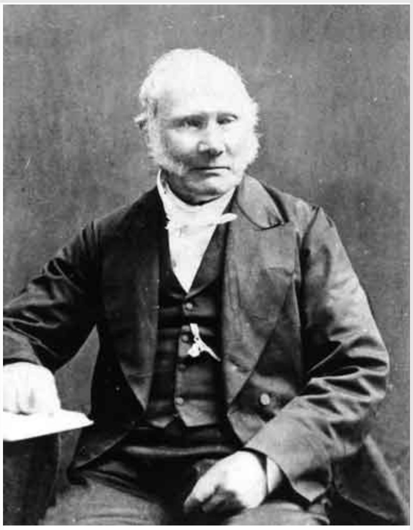

Dr. Robert Stirling

A Stirling engine is a heat engine that is operated by a cyclic compression and expansion of air at different temperatures, such that there is a net conversion of heat energy to mechanical work. More specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid.

The Stirling engine was originally designed by Dr. Robert Stirling (1790 – 1878).

Application

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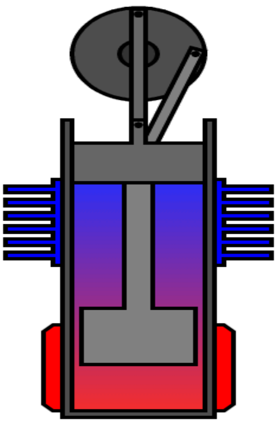

Principle of the Sterling Engine

PHYWE's Stirling engine has only one cylinder, hot at one end and cold at the other. A loose-fitting displacer shunts the air between the hot and cold ends of the cylinder. A power piston at the open end of the cylinder drives the flywheel.

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Other information (1/2)

Prior knowledge

Scientific principle

The cycle consists of four thermodynamic processes / Carnot circle

- Isothermal heat addition (expansion).
- Isochoric heat removal (constant volume).
- Isothermal heat removal (compression).
- Isochoric heat addition (constant volume).

Wheras the Stirling circle have perpendicular lines, in real applications as PHYWE's Stirling Engine this cycle is quasi-elliptical.

Other information (2/2)

Learning objective

What you can learn about …

- First and second law of thermodynamics
- Reversible cycles Isochoric and isothermal changes
- Gas laws
- Efficiency
- Conversion of heat
- Thermal pump
- Carnot cycle

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Other information (2/2)

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Principle

The Stirling engine is submitted to a load by means of an adjustable torque meter, or by a coupled generator. Rotation frequency and temperature changes of the Stirling engine are observed. Effective mechanical energy and power, as well as effective electrical power, are assessed as a function of rotation frequency. The amount of energy converted to work per cycle can be determined with the assistance of the pV diagram.

The efficiency of the Stirling engine can be estimated.

Safety instructions

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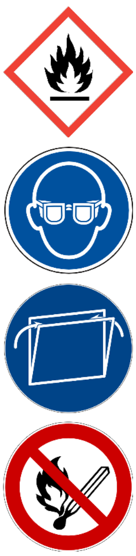

- **Ethanol / Denaturated alcohol**

  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.

  H225: Highly flammable liquid and vapour.

  H318: Causes serious eye damage.

  P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking

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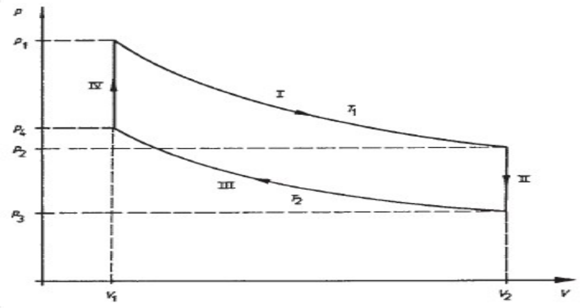
Theory (1/6)

In 1816, Robert Stirling was granted a patent for a hot air engine, which is known today as the Stirling engine. In our times, the Stirling engine is used to study the principle of thermal engines because in this case the conversion process of thermal energy to mechanical energy is particularly clear and relatively easy to understand.
At present, the Stirling engine is undergoing a new phase of further development due to its many advantages.
Thus, for example, it constitutes a closed system, it runs very smoothly, and it can be operated with many different heat sources, which allows to take environmental aspects into consideration, too.

Theoretically, there are four phases during each engine cycle.



pV diagram for the ideal Stirling process

Theory (2/6)

I) An isothermal modification when heat is supplied and work produced: $V_1 \rightarrow V_2; p_1 \rightarrow p_2; T_1 = const.$

II) An isochoric modification when the gas is cooled: $T_1 \rightarrow T_2; p_2 \rightarrow p_3; V_2 = const.$

III) An isothermal modification when heat is produced and work supplied: $V_2 \rightarrow V_1;\ p_3 \rightarrow p_4;\ T_2 = const.$

IV) An isochoric modification when heat is supplied to the system: $T_2 \rightarrow T_1; p_4 \rightarrow p_1; V_1 = const$

According to the first law of thermodynamics, when thermal energy is supplied to an isolated system, its amount is equal to the sum of the internal energy in- crease of the system and the mechanical work supplied by the latter:

$$dQ = dU + pdV$$

It is important for the Stirling cycle that the thermal energy produced during the isochoric cooling phase be stored until it can be used again during the isochoric heating phase (regeneration principle).

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Theory (3/6)

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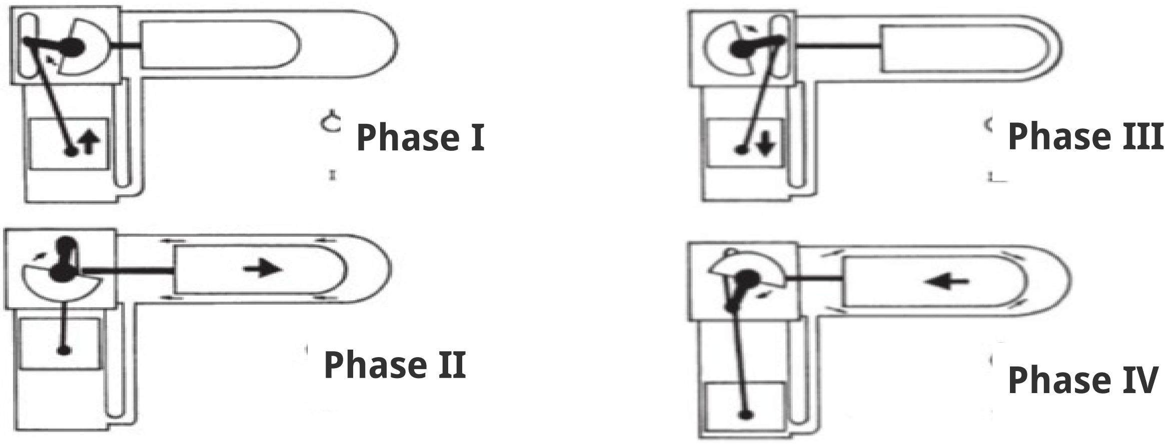

Functioning of the Stirling engine, Phase I, II, III, IV

Theory (4/6)

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Thus, during phase IV the amount of thermal energy released during phase II is regeneratively absorbed. This means that only an exchange of thermal energy takes place within the engine. Mechanical work is merely supplied during phases I and III. Due to the fact that internal energy is not modified during isothermal processes, work performed during these phases is respectively equal to the absorbed or released thermal energy.

Since

$$p \cdot V = \nu \cdot R \cdot T$$

where ν is the number of moles contained in the system, and R the general gas constant.

The amount of work produced during phase I is:

$$W_1 = -n \cdot R \cdot T_1 \cdot ln(V_2/V_1)$$

(negative, because this amount of work is supplied).

Consequently, the amount of work supplied during phase III is:

$$W_3 = +\nu \cdot R \cdot T_2 \cdot ln(V_2/V_1)$$

$|W_1| > W_3$ because $T_1 > T_2$

Theory (5/6)

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Consequently, the amount of work supplied during phase III is

$$W_3 = +\nu \cdot R \cdot T_2 \cdot ln(V_2/V_1)$$

$|W_1| > W_3$ because $T_1 > T_2$

The total amount of work is thus given by the sum of W_1 and W_3. This is equal to the area of the pV diagram:

$$W_t = W_1 + W_3$$

$$W_1 = -\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)$$

Only part of this total effective energy W_t is used as effective work W_m through exterior loads applied to the engine. The rest contains losses within the Stirling engine.

The maximum thermal efficiency of a reversible process within a thermal engine is equal to the ratio between the total amount of work W_1 and the amount of supplied thermal energy $Q_1 = -W_1$

$$\eta_{th} = W_t/W_1$$

$$\eta_{th} = \frac{\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)}{\nu \cdot R \cdot T_1 \cdot ln(V_2/V_1)}$$

$$\eta_{th} = \frac{T_1 - T_2}{T_1}$$

Carnot found this to be the maximum thermal efficiency for any thermal engine, which can only be reached theoretically. One sees that efficiency increases with increasing temperature differences.

Theory (6/6)

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Only part of this total effective energy W_t can be used as effective work W_m through exterior loads applied to the engine.

The remaining part contains losses within the Stirling engine.

The maximum thermal efficiency of a reversible process within a thermal engine is equal to the ratio between the total amount of work $|W_1|$ and the amount of supplied thermal energy $Q_1 = -W_1$

$$\eta_{th} = W_t/W_1$$

$$\eta_{th} = \frac{\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)}{\nu \cdot R \cdot T_1 \cdot ln(V_2/V_1)}$$

$$\eta_{th} = \frac{(T_1 - T_2)}{T_1}$$

Carnot found this to be the maximum thermal efficiency for any thermal engine, which can only be reached theoretically.
Efficiency increases with increasing temperature differences.

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Equipment

Position	Material	Item No.	Quantity
1	Stirling engine transparent	04372-00	1
2	Stirling Engine Datalogging Module	04372-10	1
3	measureLAB, multi-user license	14580-61	1
4	Motor/ generator unit	04372-01	1
5	Torque meter	04372-02	1
6	Chimney for stirling engine	04372-04	1
7	Rheostat, 330 Ohm , 1.0A	06116-02	1
8	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C…760°C	07122-00	2
9	Connecting cord, 32 A, 500 mm, red	07361-01	2
10	Connecting cord, 32 A, 500 mm, blue	07361-04	3
11	Graduated cylinder, 50 ml, plastic	36628-01	1
12	Denaturated alcohol (spirit for burning), 1000 ml	31150-70	1
13	Lamp 4 V/0.1 A, E10	06153-00	5

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Setup and procedure

Tasks

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Tasks

- Setup of the experiment
- Calculation of the total energy produced by the Sterling engine
- Assessment of the mechanical work per revolution, and calculation of the mechanical power output as a function of the rotation frequency, with the assistance of the torque meter.
- Determination of the burner’s thermal efficiency
- Assessment of the electric power output as a function of the rotation frequency.
- Efficiency assessment.

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Setup (1/2)

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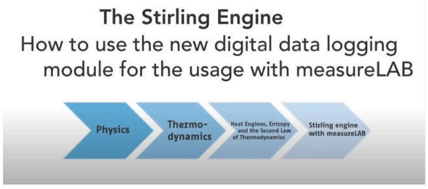
Videos for setup the experiment

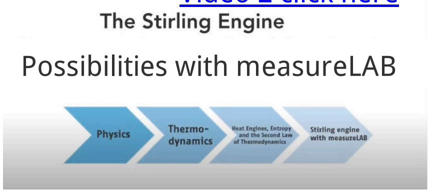
in an easy way you may perform the setup following the included video.

Video 1 click here



The Stirling Engine: How to mount the data logging module for the usage with measureLAB

Video 2 click here



The Stirling Engine: Possibilities with measureLAB

Video 3 click here

The Stirling Engine: General overview

Setup (2/2)

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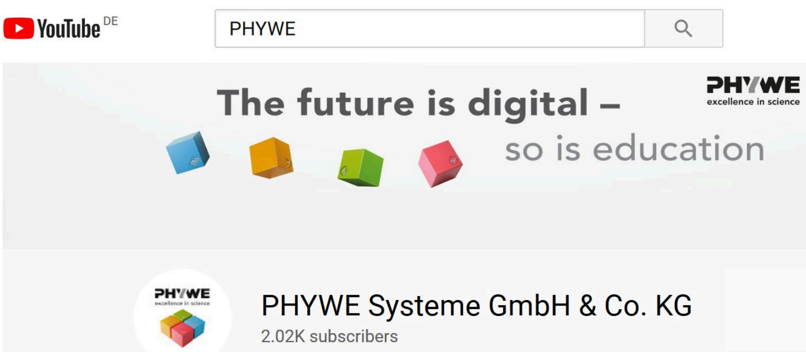
Please also sign up for the YouTube PHYWE channel

You never will miss in future new info for relevant purposes

https://www.youtube.com/c/phywesysteme/featured to subscribe just click here



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Procedure

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Presentation and drawing of the pV diagram

- Connect the module to the PC via USB and then start measureLAB.
- Select "Quick Start", then use P-V Mode
- Rate should be set to 2 kHz
- Curve settings: Linewidth: 6 Symbol Points
- Place the lighted burner below the glass cylinder, and observe the temperature display.
- Do not forget the glass chemney.
- When the temperature difference has reached approximately 80 K, give the flywheel a slight clockwise push to start the engine.

Manual

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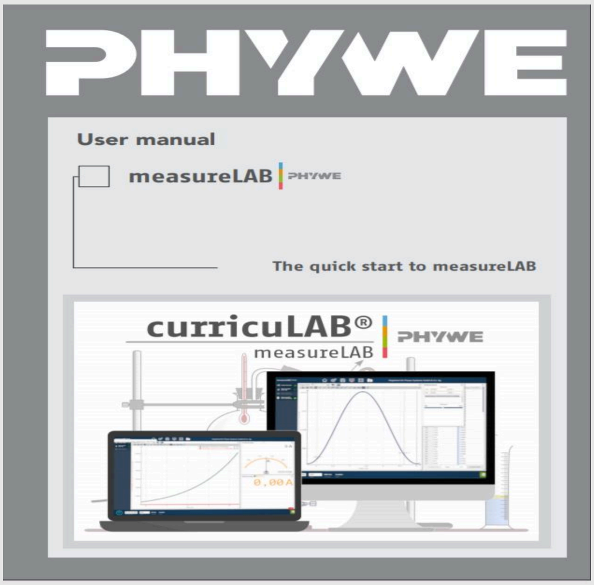

Usage of measureLAB

- The usage of the software is is extensively discribed in the "User Manual"
- You will find this manual by pressing the following button within the measureLAB software

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Evaluation (1/3)

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Spirit burner, adjustable 32154-00

Estimation of the thermal power of the burner (see photo) is given below.

Amount of alcohol burned $\Delta V = 29ml$

Alcohol density $\rho = 0.83g/ml$

This allows to determine the mass of alcohol burnt per second:

$$\frac{\Delta m}{\Delta t} = 6.69 \cdot 10^{-3}\ \mathrm{g/s}$$

as well as the thermal power of the burner:

$$P_H = 167\ \mathrm{W}$$

Evaluation (2/3) - Typical pV Curve from PHYWE

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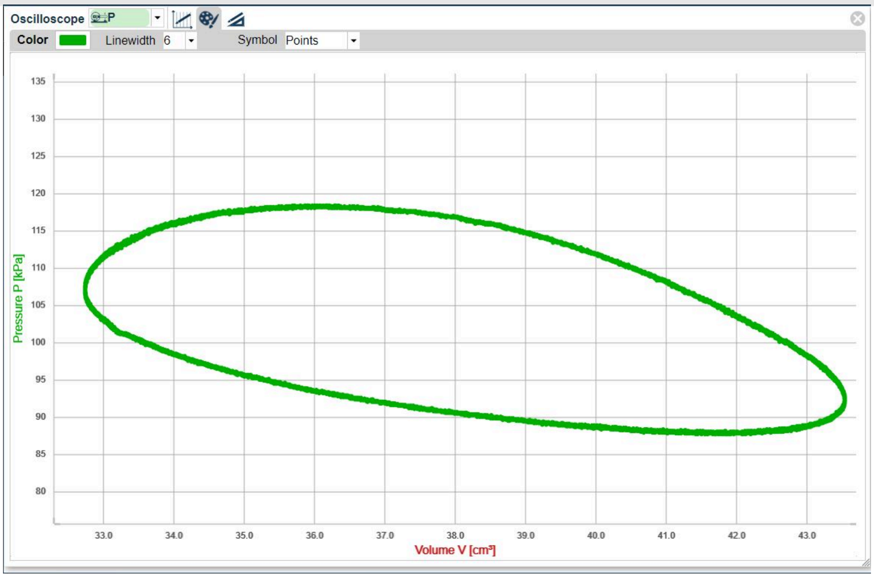

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Evaluation (3/3) - Typical pV Curve from PHYWE

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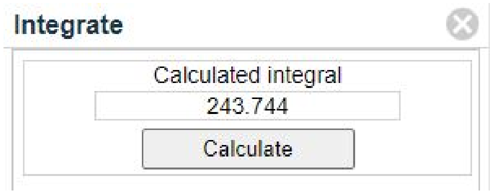
After recording the pV curve you can after cliquing the "Tools and analysis" button determine using the "Integration function" determine the value of the integral.

With this tool you can determine the surface of the curve necessary to determie the efficiency of the Sterling Engine



Alternative setup

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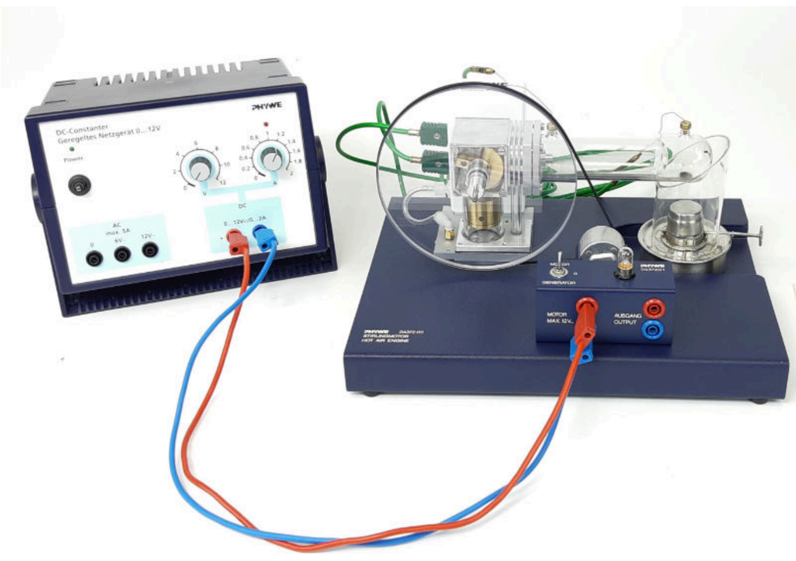
Experimental setup

With an external power supply (e.g. PHYWE power supply, 230 V, 13506-93) providing DC: 0...12 V, 2 A you can inverse the Carnot cycle by feeding the unit with 5 - 10 VDC, 1.5 A according to the photo shown.

Note the power supply is not part of the articles provided with the experiment, and have to be purchased separately.



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