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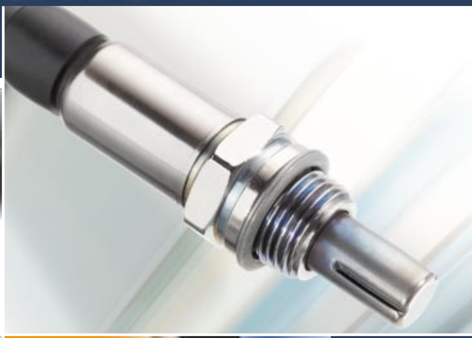

Everything About Oxygen-Sensors

Technical
Information
No. 03

Perfection
built in

BERU

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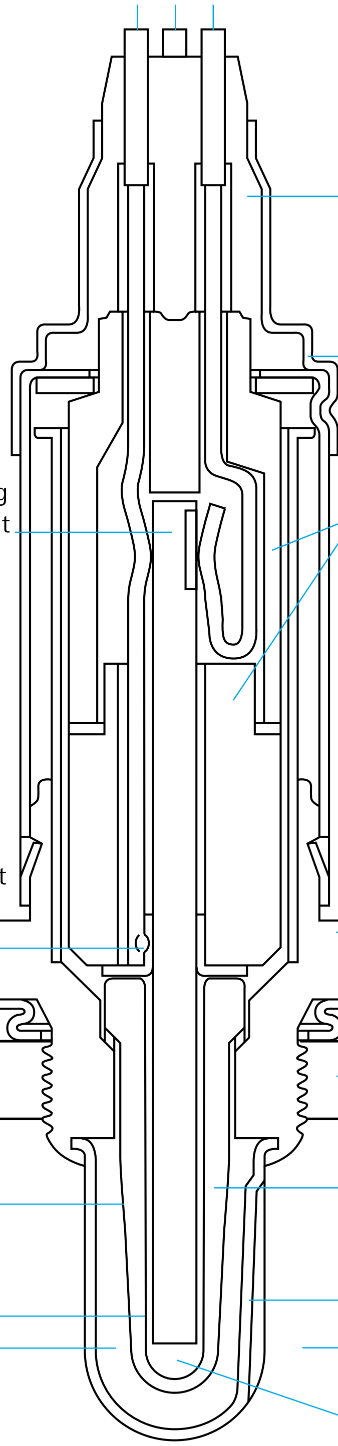
Cross-Section of an Oxygen Sensor



Introduction

For the perfect combustion of the gasoline in an Otto motor, approximately 14 kg air is required per kilogram of gasoline, meaning about 11 cubic metres. The ratio of the air volume actually supplied to the theoretical air requirement is identified as the Lambda value (formula symbol λ). The statement „λ=1" therefore means that the air volume which is optimum for combustion is supplied. It is nevertheless to be remembered that the Otto motor reaches its highest power at 0-10 % air deficiency (therefore at λ=0.9 to λ=1.0) - and the lowest fuel consumption is achieved with about 10 % air excess (therefore $\lambda \approx 1.1$).

Considering the fuel-air mixture, a distinction is made between a „rich mixture" (with a relatively high share of fuel) and a „lean mixture" (with a relatively high share of air). In the exhaust gases of a very rich mixture, the proportion of carbon monoxide and hydrocarbons is very high and decreases with increasing values of Lambda. The proportion of nitrogen is relatively low with a rich mixture and only achieves its maximum value at λ=1. On the other hand, the proportion of the air and thereby the proportion of oxygen in the exhaust gas is relatively high with lean mixtures.

With an optimum catalyst, the carbon monoxide present is converted to carbon dioxide through oxidation with oxygen. Nevertheless, too little CO is left over for the conversion of nitrogen monoxide into elementary nitrogen. Catalytic exhaust gas purification is therefore not only a question of a suitable catalyst, but also one of the particular optimum exhaust gas composition.

The three-way catalytic converter was developed for this purpose. It simultaneously converts carbon monoxide, hydrocarbons and nitrogen oxide in a reactor. The exhaust gas composition required for this is achieved through an electronically controlled adjustment of the fuel-air mixture.

A requirement for this is permanent measurement of the oxygen content in the exhaust gas. The Lambda sensor performs this measurement.

The value measured indicates how complete or incomplete the fuel-air mixture is burned in the motor.

The Oxygen sensor determines the exhaust gas concentration through a comparative oxygen measurement: The oxygen content of the outside air is compared with the remaining oxygen in the exhaust gas. These differences are transmitted further to the control unit through a voltage signal. The control unit then corrects the ignition and the injection appropriately.

Through the heavy loading of the Oxygen sensor in the exhaust gas flow, it is subject to natural wear.

In the exhaust gas measurement, which takes place at a defined interval, the function of the Oxygen sensor is measured and possible wear detected. The sensor should be replaced after approx. 60,000 to 80,000 km of service.

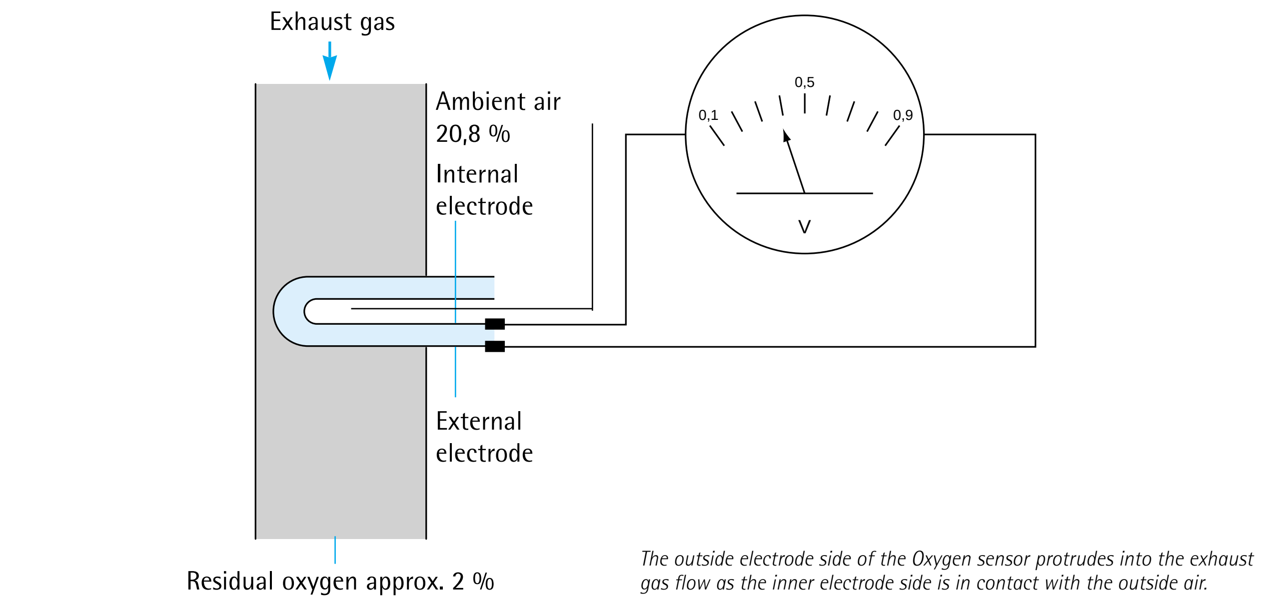
The Principle of Comparative Oxygen Measurement

The oxygen content of the ambient air is normally about 20.8%. This reference value is compared with the remaining oxygen at the Oxygen sensor.

If there is a remaining oxygen content of 2% („lean mixture") in the exhaust gas flow, a voltage of about 0.1 Volt results because of the difference in comparison with the ambient oxygen.

If less than 2 % remaining oxygen is contained in the exhaust gas flow („rich mixture"), this increased difference to the outside oxygen can be seen in a sensor voltage of approx. 0.9 Volt.

Example: Residual O_2 = 2 %
Outside electrode is located in exhaust gas flow (Residual O_2 = 2 %)
Inside electrode is connected with the ambient air (O_2 = 20,8 %)



The outside electrode side of the Oxygen sensor protrudes into the exhaust gas flow as the inner electrode side is in contact with the outside air.

Structure and Function of an Oxygen Sensor

The Oxygen sensor consists essentially of a special ceramic body, its surface is provided with gas-permeable platinum electrodes. The effect of the sensor is based on two physical factors: On the one hand, the ceramic material is porous and permits diffusion of the oxygen in the air. On the other hand, the ceramic becomes conductive at temperatures of approx. 300 °C. The oxygen content of the air is measured on both sides of the electrodes. If the difference changes, an electrical voltage, which varies in the millivolt range, is produced on the electrodes.

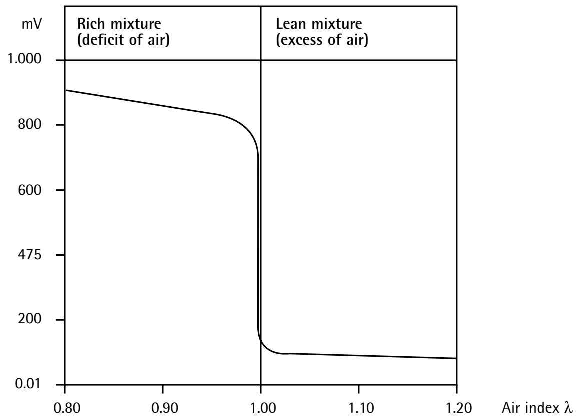
With Oxygen sensors, there are various principles of operation: Titanium oxide sensors change the resistance while zirconium sensors change the voltage. As the latter are used mostly, they are described as follows:

A ceramic part (solid electrolyte) is placed in a steel housing. The outer part of the ceramic body is located in the exhaust gas flow. The inner part is in contact with the outside air.

The migration of electrons causes a stepwise increase in the sensor voltage. This voltage jump is used as the Lambda control.

Lambda < 1 = rich mixture
V-Lambda approx. 0.9 Volt

Lambda > 1 = lean mixture
V-Lambda approx. 0.1 Volt



Sensor Heating and Cabling

To bring the sensor quickly to operating temperature after starting the motor, heated sensors are used. They exhibit not only one, but three or four electrical connections.

In the case of sensors with three electrical connections, the ground for the heating element is connected through. In the case of sensors with four connections, the signal ground and the heating element ground are separated. This avoids interference, which can occur on the ground connections through corrosion and seals.

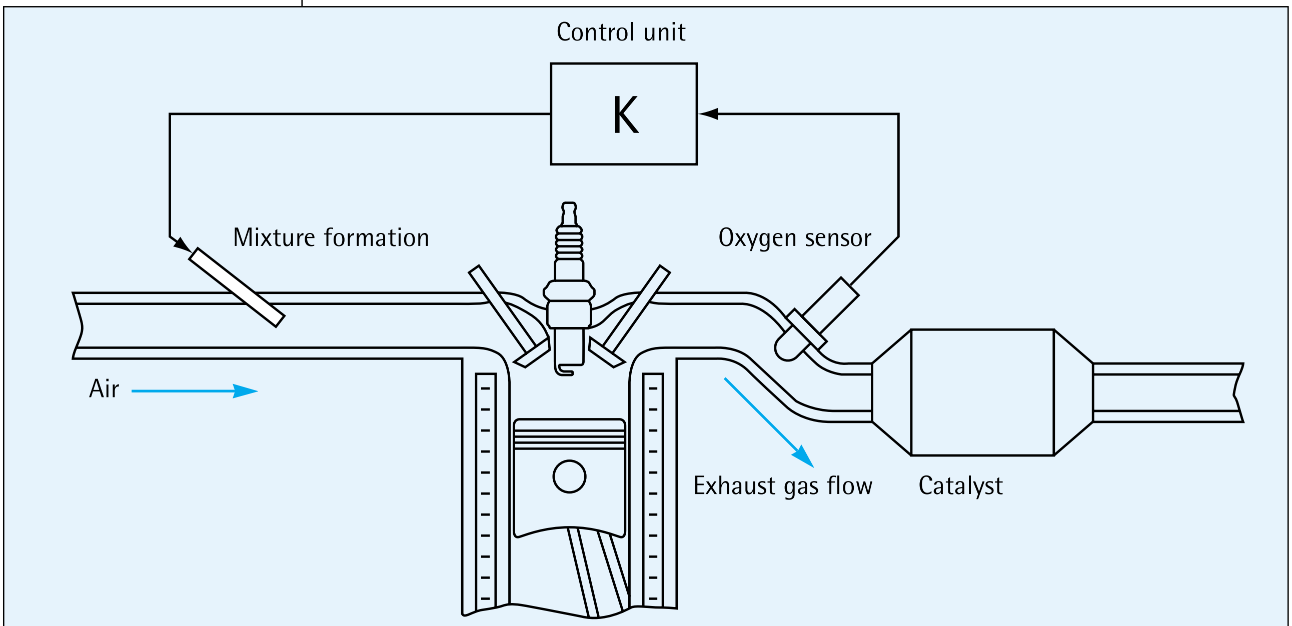
- Oxygen sensor with 1 cable
  Cable colour:
  Black = Signal for control unit
- Oxygen sensor with 3 cables
  Cable colours:
  Black = Signal for control unit
  2 x white = Power supply for sensor heating
- Oxygen sensor with 4 cables
  Cable colours:
  Black = Signal for control unit
  2 x white = Power supply for sensor heating
  Grey = Ground

Basic Principle of the Lambda Controller

When the Oxygen sensor signals „lean mixture" to the control unit, the controller enriches the mixture.

When the Oxygen sensor signals „rich mixture" to the control unit, it leans out the mixture.

The Oxygen sensor is built into the exhaust gas pipe upstream of the catalyst so that the composition of the mixture moves permanently in the Lambda window (meaning in the range which is necessary for the optimum effect of the catalyst). It provides information on whether the Lambda air index is greater than 1 or less than 1 to the control unit. It influences the composition of the mixture through the mixture formation and thereby the Lambda air index.



Testing of the Oxygen Sensor

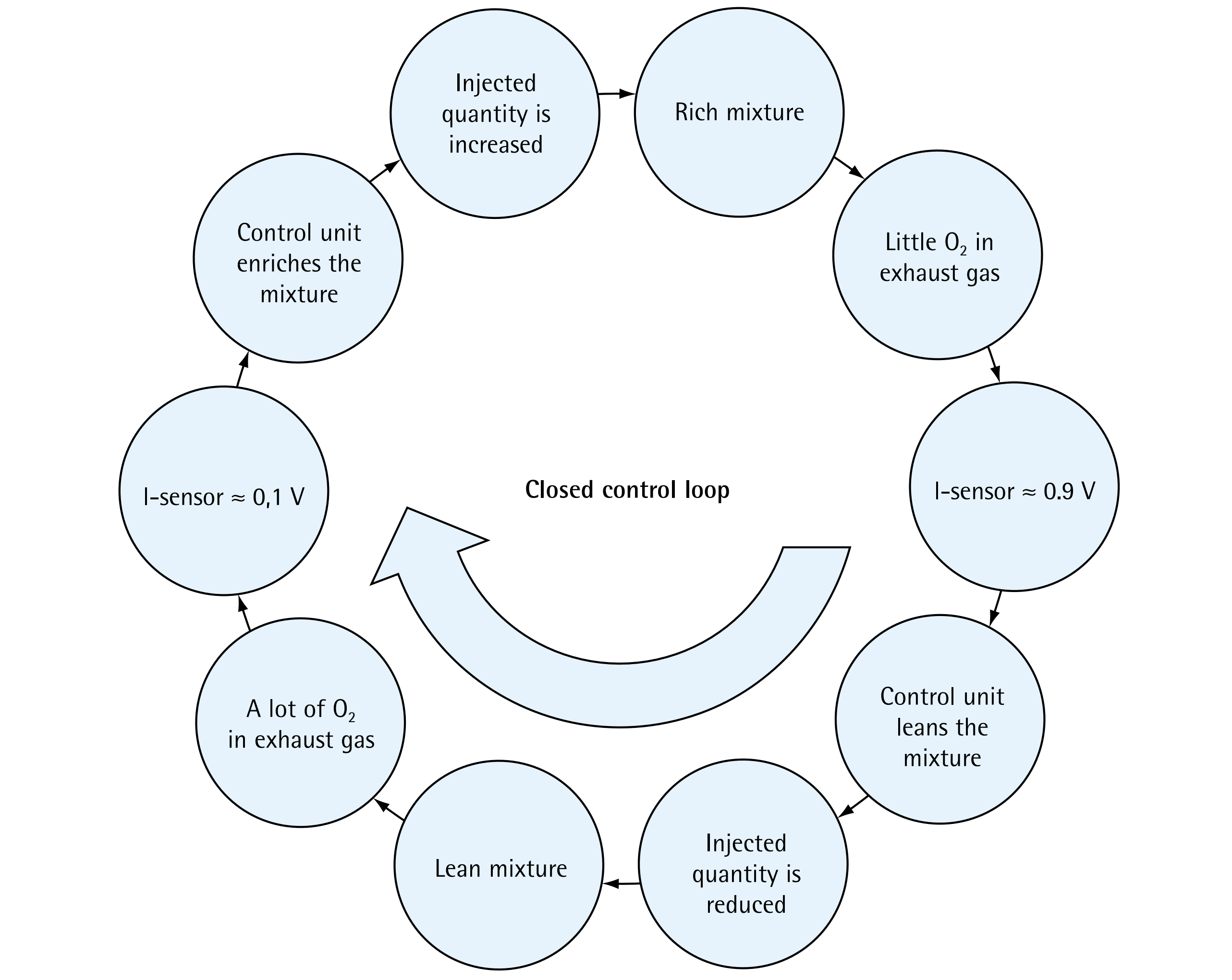
The closed control loop

For the Oxygen sensor to reach its threshold temperature of approx. 250-300 °C, the motor and the sensor must reach the hot operating condition. After this, separate the connection plug of the Oxygen sensor from the control unit, insert the appropriate adapter plug between them and make the connection to the control unit again

The function of the Oxygen sensor is measured using a voltmeter - we recommend a voltmeter with an analog display as the voltage jumps can be read better with it.

The voltmeter must swing back and forth between 0.1 and 0.9 Volt with the motor and the sensor in hot operating condition.

The closed control loop can be made visible in the following way: If the voltage on the voltmeter amounts to 0.1 Volt, there is a lean mixture in the exhaust gas pipe and the sensor sends a signal to the control unit to enrich the mixture. If the voltmeter displays 0.9 Volt, there is a rich mixture in the exhaust gas pipe and the sensor sends a signal to the control unit to lean the mixture.

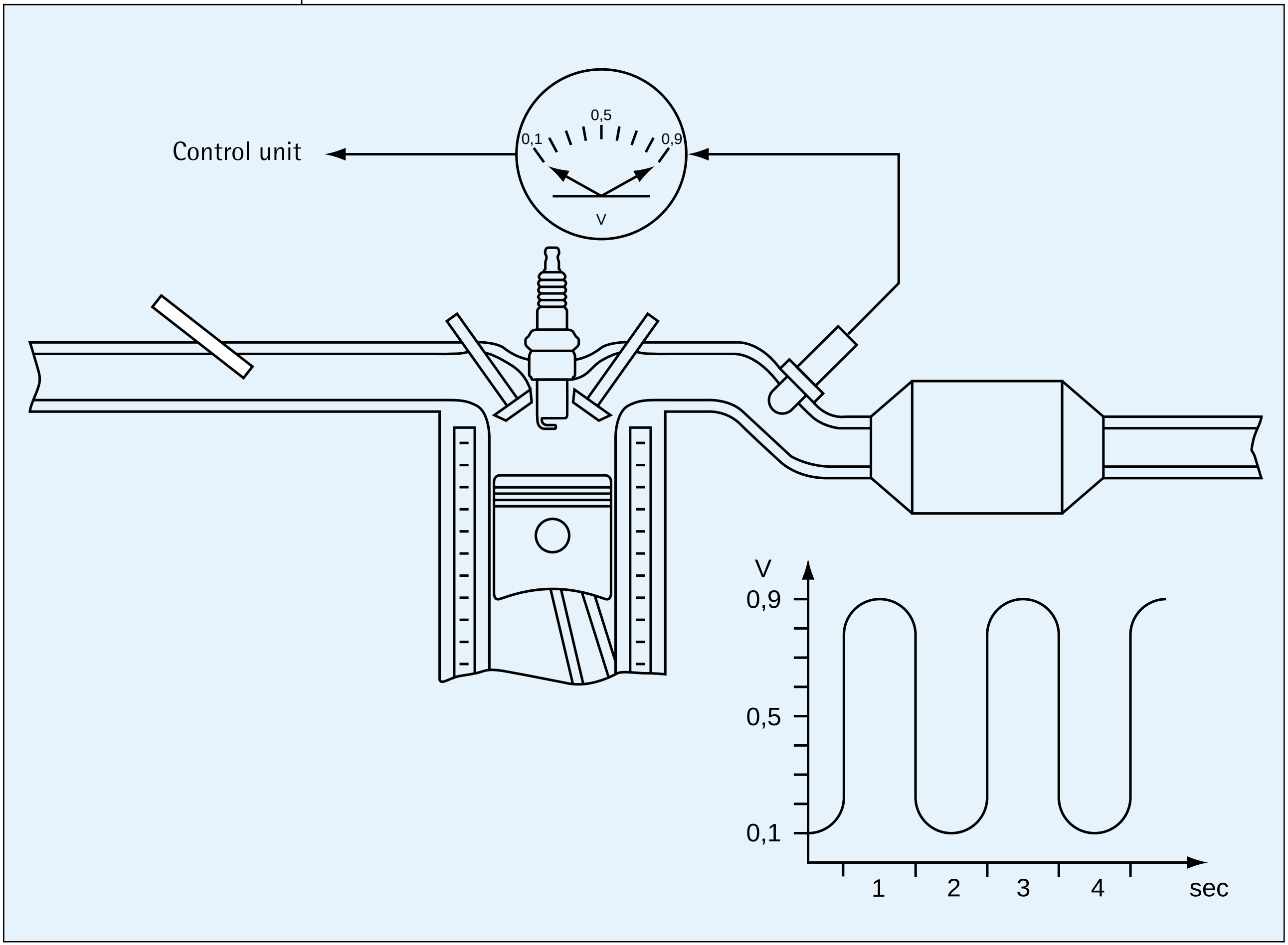


Check of the Oxygen Sensor

With increasing total use, the platinum coating of the sensor becomes inactive through chemical and thermal erosion. The voltage emitted then moves toward lower voltage values. When the reference voltage of 0.5 Volt is no longer exceeded, the „rich mixture" information is no longer transmitted to the control unit – and the control unit enriches the mixture continuously.

The sensor heating can also fail. The result is a long delay in reaching the operating temperature - and thereby a failure of the regulation over wide operating ranges, such as short distances and idling.

Does the voltage vary between 0.1 and 0.9 Volt? Then the sensor is OK.



Troubleshooting for the Lambda regulation

The electrical testing of the Lambda control takes place in a closed control loop. Requirements for the testing are:

- The motor must be in hot operating condition.
- The Oxygen sensor must be in hot operating condition (approx.250 °C) and this information must be available to the control unit. (Attention: Defects on the coolant temperature sensor can, especially in case of an interruption, cause the control unit to receive incorrect information - such as „Motor temperature under 70°C, for example.)
- If sensor heating is installed, it must be connected and able to function.
- An analog voltmeter is required.

Procedure:
Warm up the motor, loosen the connecting plug between the Oxygen sensor and the control unit and insert the adapter plug in between. (Our tip: If an adapter is not available, you can make one using normal commercially-available connectors.)

Check of the Lambda Regulation in an Open Control Loop

If a fault occurs in the testing of the Lambda regulation in the closed control loop, an examination must then be performed to determine whether all conditions (such as motor temperature, sensor temperature, temperature sensors, etc.) fulfill the requirements. If this is the case, electrical test signals are suggested, whereby a voltage is applied to the control unit through an external voltage source. It simulates a lean or a rich mixture for it. If the control unit and the cable connections are in order, the control unit will attempt to change the mixture in accordance with the signal applied.

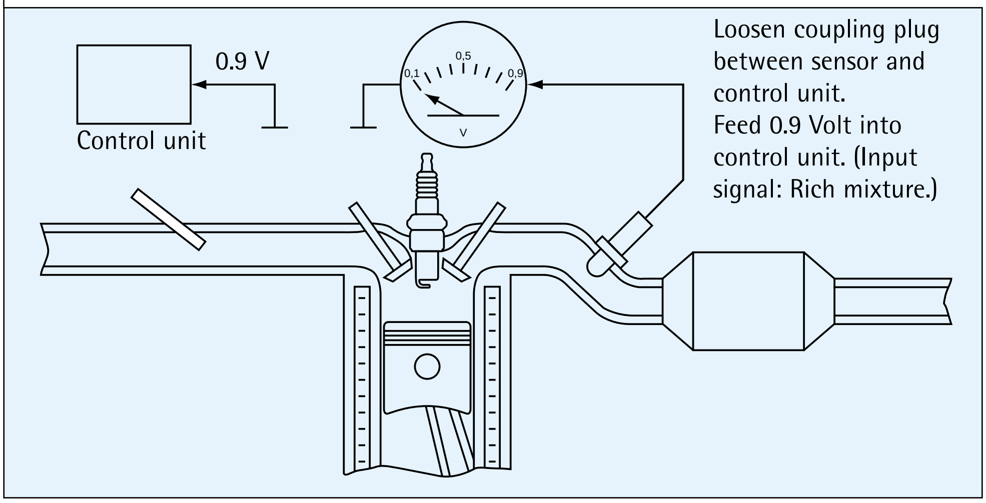
This procedure can be observed easily with the exhaust gas measurement device or acoustically: With a richer mixture, the motor runs more smoothly and it tends to run roughly with a leaner mixture. An Oxygen sensor, able to function, changes its voltage accordingly.

Input signal: Rich mixture
The control unit attempts to lean out the mixture. The motor running becomes rougher. The sensor voltage must vary about 0.1 Volt.

If the running of the motor doesn't change? Then check the temperature sensor, cable harness and control unit. Replace defective parts!

If the sensor voltage doesn't change? Either the sensor is too cold – then warm up.

Does the fault still occur in spite of a hot sensor? Then the sensor is defective, the sensor heating no longer functions – or there is a grounding fault. In every one of these cases, replace the sensor without fail!

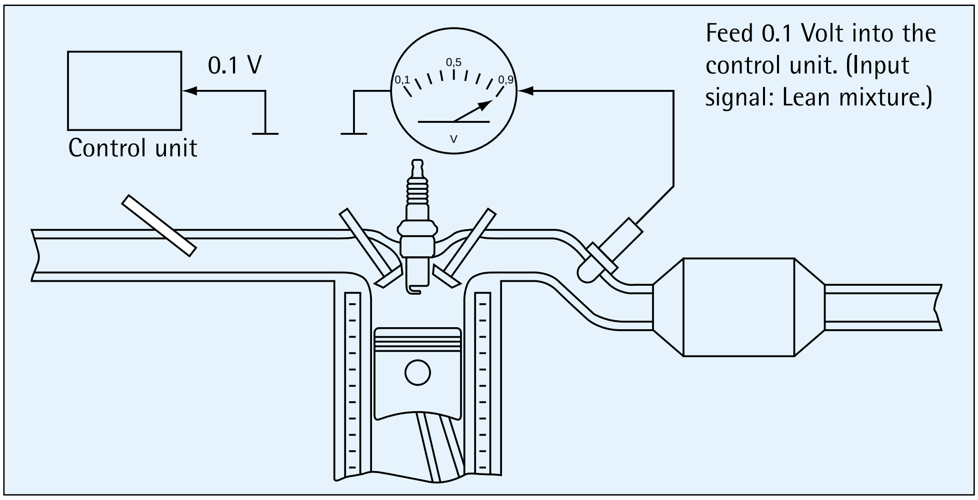


Input signal: lean mixture
The control unit attempts to enrich the mixture and motor running becomes smoother. The sensor voltage must amount to approx. 0.9 Volt.

If the running of the motor doesn't change? Then check the temperature sensor, cable harness and control unit. Replace defective parts!

If the sensor voltage doesn't change? Either the sensor is too cold – then warm up.

Does the fault still occur in spite of a hot sensor? Then the sensor is defective, the sensor heating no longer functions – or there is a grounding fault. In every one of these cases, replace the sensor without fail!

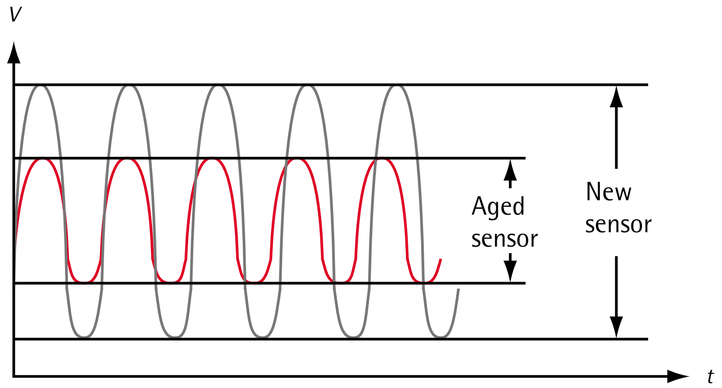


Is a voltage of only 0.7 Volt reached? Then the sensor has aged and must be replaced.

Is there an air leak? Then the exhaust gas system is not tight. Check for tightness.

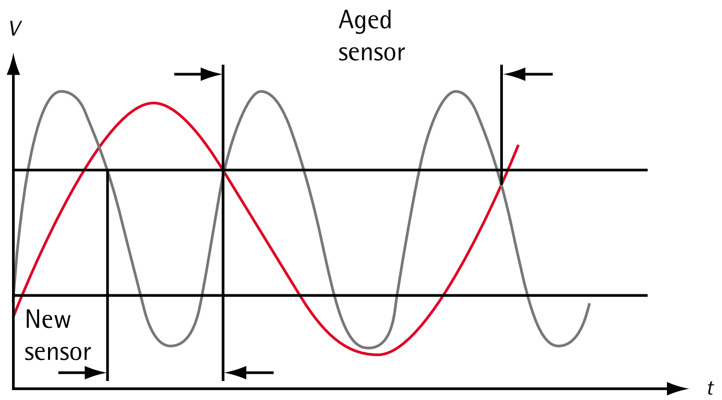
Comparison of a new Oxygen sensor with an aged Oxygen sensor – with respect to mixture recognition, response time and control frequency

Amplitude:



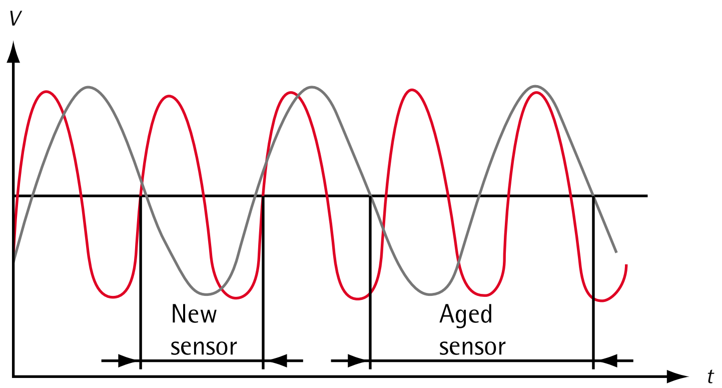
Maximum 0.9 and minimum 0.1 are no longer reached; rich/lean recognition is no longer possible.

Response time:



Sensor reacts too slowly to changes in the mixture and no longer indicates the actual status at the exact time.

Duration of period:



The frequency of the sensor is too slow and optimum regulation is no longer possible.

Conversion of Pollutants

The conversion of the pollutants takes place in the catalyst. A catalyst is a material which promotes and/or accelerates a chemical reaction without taking part in it itself.

Oxidation = Combination with oxygen
Reduction = Removal of oxygen

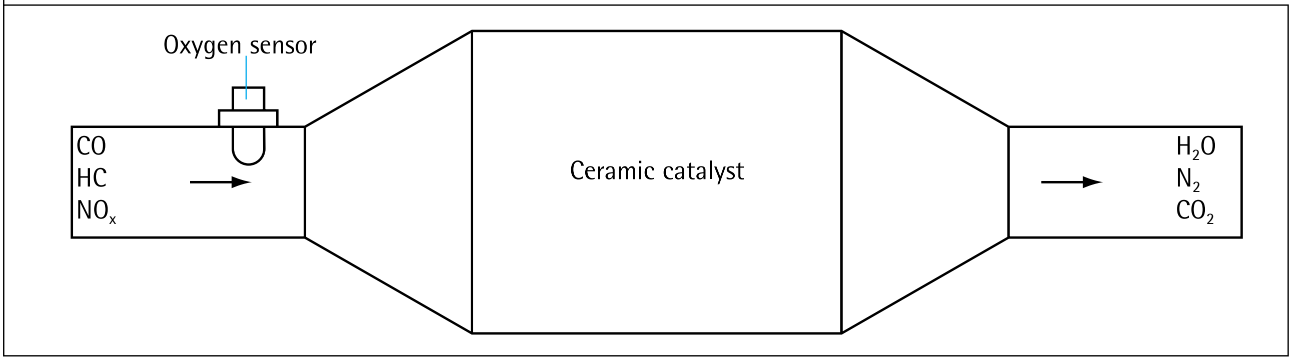
CO (Carbon monoxide) oxidizes to CO_2 (carbon dioxide)
HC (Hydrocarbon) oxidizes to H_2O and CO_2 (Water and carbon dioxide)

NO_x (Nitrogen oxide) reduces N_2 and O_2 (Nitrogen and oxygen)

In order for an oxygen pulse to result, the Oxygen sensor must make the mixture

- leaner
- richer

The conversion rate, meaning the proportion of converted pollutants amounts to 90-95 % in modern catalysts.



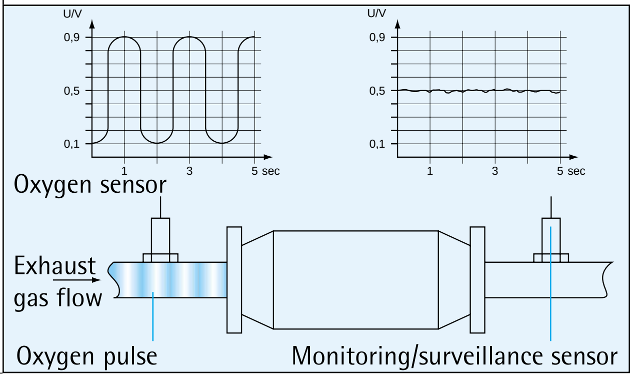
Monitoring and Analysis of the Condition of the Catalyst

A second Oxygen sensor (called the monitoring or surveillance sensor) is located behind the catalyst. This monitoring/surveillance sensor is not any different in structure and function from the Lambda control sensor installed upstream of the catalyst. This means that both sensors emit a voltage – depending upon the remaining oxygen content. As permanent mixture corrections in the direction of richer and leaner mixtures take place constantly during the operation of a Lambda-controlled motor, the residual oxygen content in the exhaust gas varies accordingly (oxygen peaks), through which voltage peaks are continuously triggered in the sensor. Through the high storage capacity of new catalysts for oxygen, the change of the oxygen content after the catalyst is almost completely damped. As a result of this, the control sensor indicates the oxygen variations through corresponding voltage jumps, while the voltage of the monitor sensor is almost constant.

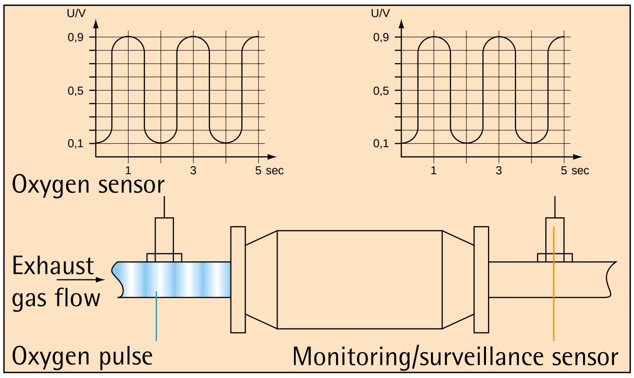
With increasing age of the catalyst, its ability to store oxygen decreases, through which the damping of the oxygen variations also decreases. This process can be measured on the monitor sensor downstream of the catalyst.

With advanced ageing of the catalyst, the development of the signal on the monitor sensor is almost identical to the development of the signal on the control sensor.

Catalyst is OKO



Catalyst defective



Typical Defects on Oxygen Sensors

The most frequent causes of failure with Oxygen sensors

Diagnosis	Cause
Overheating	Temperatures above 950 °C through irregular combustion, the incorrect ignition point or incorrect valve timing
Chemical ageing	Too frequent short trips
Air leakage	Sensor not installed properly
Poor ground connections	Oxidation in the exhaust pipe
Poor connection contacts	Oxidation in the plug connection
Ceramic and deposits are damaged	Too large tightening torque of the sensor
Lead deposits	Presumably the use of leaded fuel
Interrupted Lambda cable connection	Rodent bite
Clogging of the sensor body through oil residues	Unburned oil in motor, e.g. through worn piston rings or valve shaft seals

What the status of the protective pipe tube indicates

In addition to checking the connection lines, the plug and the sensor housing, the protective pipe of the sensor element must also be checked for deposits. The most important symptoms are:

Symptom	Cause	Elimination
Thick carbon deposits on the protective pipe	Too rich fuel-air mixture, defective Oxygen sensor heater	Replace sensor, otherwise there is a danger of clogging and thereby reduction of the reaction speed
Shiny deposits on the protective pipe	Use of leaded fuel, through which the platinum coatings of the Oxygen sensor and possibly the catalyst are attacked and destroyed	Replace sensor without fail, check catalyst
Light deposits on the protective pipe	Oil in combustion chamber or the use of certain fuel additives	Replace sensor without fail, check catalyst, and check motor for loss of oil

Thick carbon deposits on protective pipe

Light deposits

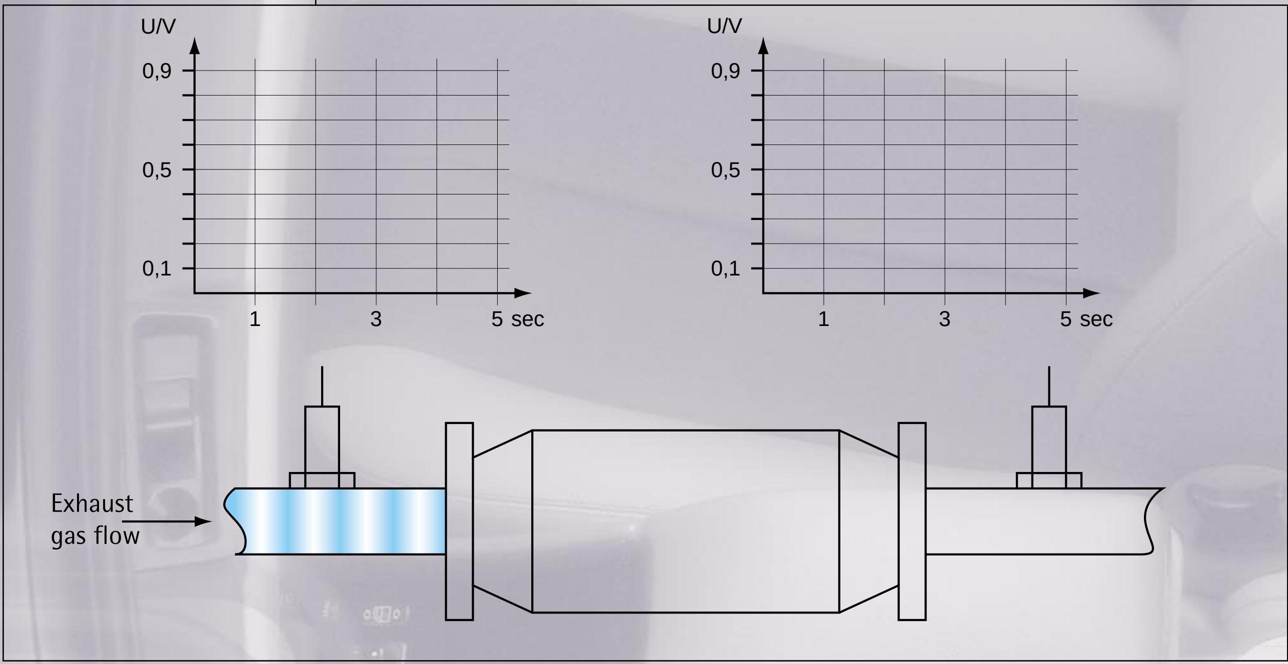
Improper installation

To avoid damage to the Oxygen sensor during installation, please observe torque and use a special tool, if necessary.

Self Test

1

Draw the characteristic curves of an intact catalyst.
(Sensor and cat at operating temperature!)



2

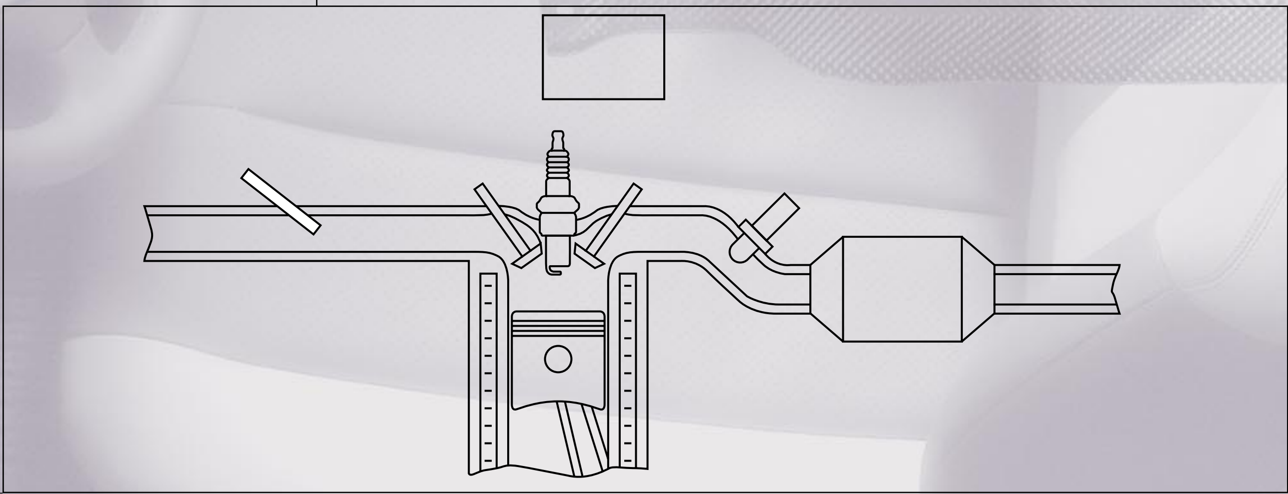
What are the names of the two Oxygen sensors ...

... in front of the cat? __________________ sensor

... after the cat? ______________________ sensor

3

Name the components of the Oxygen controller and connect them with each other!



4

At a sensor voltage of 0.1 Volt the mixture is ...

____

5

At a sensor voltage of 0.9 Volt the mixture is ...

____

6

Which three gases does the 3-way catalyst convert into non-poisonous materials?

______________________________,

______________________________ and

______________________________.

7

In which order of magnitude is the conversion rate for vehicles with regulated mixture control and catalysts?

- ☐ 10–50 %
- ☐ 60–70 %
- ☐ 90–95 %
- ☐ 100 %

8

From which temperature is reliable control operation of the Oxygen sensor guaranteed?

- ☐ approx. 10 °C
- ☐ approx. 800 °C
- ☐ approx. 250 °C
- ☐ above 900 °C

9

The motor control uses the signal from the Oxygen sensor to determine the following ...

- ☐ ... the exhaust gas composition continuously.
- ☐ ... whether the motor is running with knocking combustion.
- ☐ ... whether the fuel-air mixture must be enriched or leaned out.

10

What is the colour of the sensor signal line of the Oxygen sensor?

- ☐ White
- ☐ Grey
- ☐ Black

11

What is understood by the λ-window?

- ☐ The catalyst can only work in this range.
- ☐ In this range, the conversion of all three harmful exhaust gas components into less harmful gases is the most favourable.

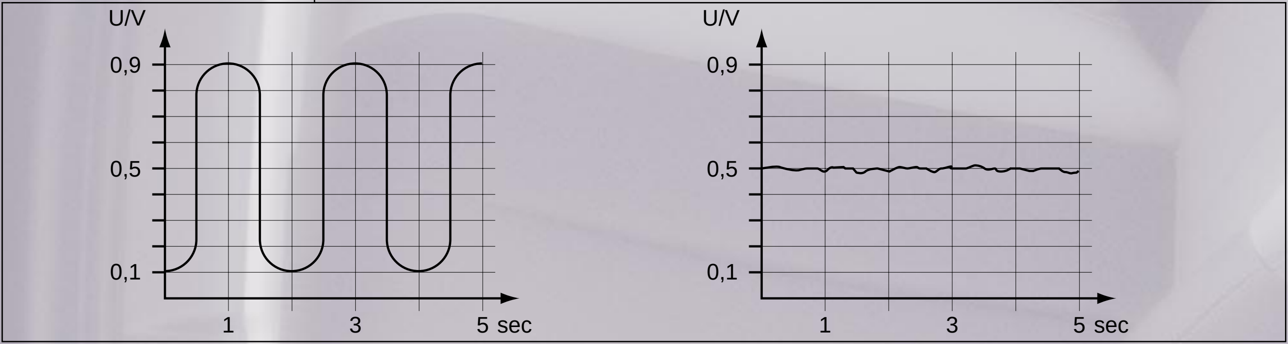
12

Which gases are defined as poisonous?

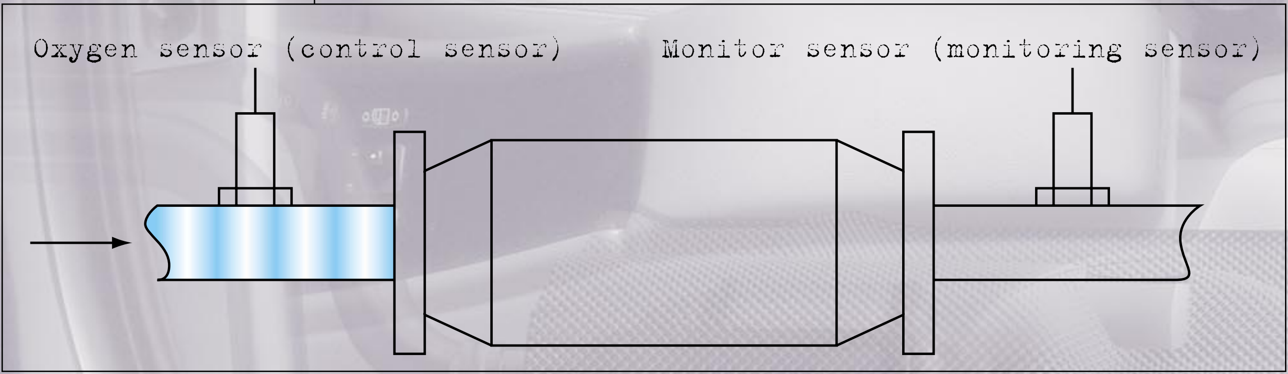
- ☐ CO
- ☐ CO_2
- ☐ CH
- ☐ NO_x
- ☐ N_2O

Solutions

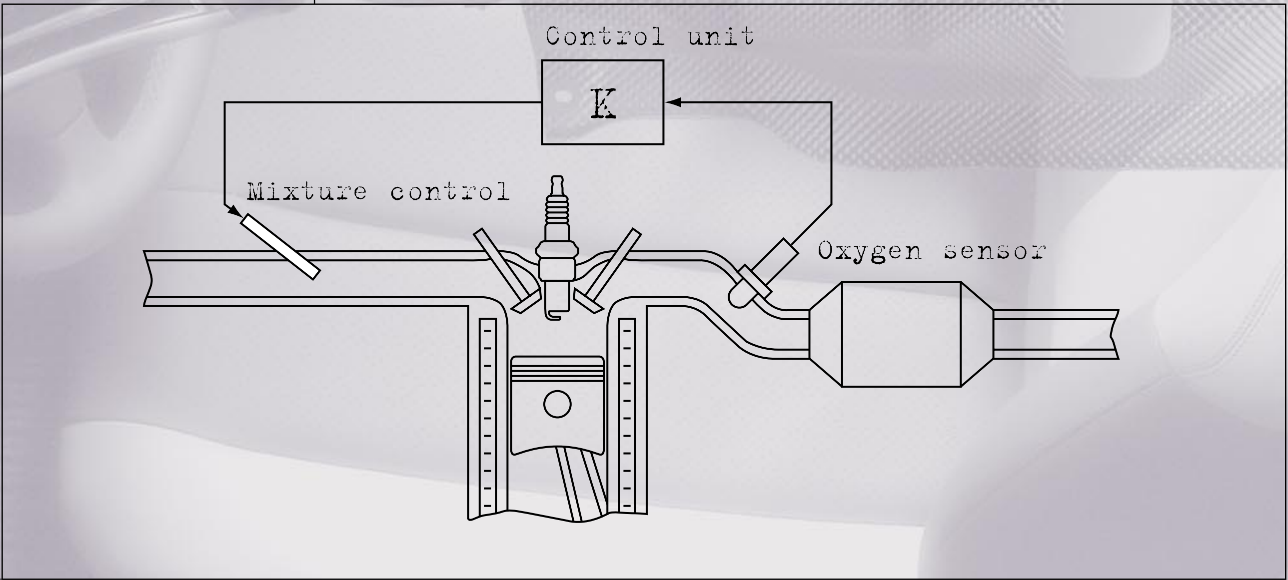
1. Draw the characteristic curves of an intact catalyst.
(Sensor and cat at operating temperature!)



2. What are the names of the two Oxygen sensors ...



3. Name the components of the Oxygen controller and connect them with each other!



4

At a sensor voltage of 0.1 Volt the mixture is ...

... lean, as the proportion of oxygen in the exhaust gas is greater.

5

At a sensor voltage of 0.9 Volt the mixture is ...

... rich, as the proportion of oxygen in the exhaust gas is smaller.

6

Which three gases does the 3-way catalyst convert into non-poisonous materials?

Carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO_x).

7

In which order of magnitude is the conversion rate for vehicles with regulated mixture control and catalysts?

- [ ] 10–50 %
- [ ] 60–70 %
- [X] 90–95 %
- [ ] 100 %

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From which temperature is reliable control operation of the Oxygen sensor guaranteed?

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- [X] NO_x
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