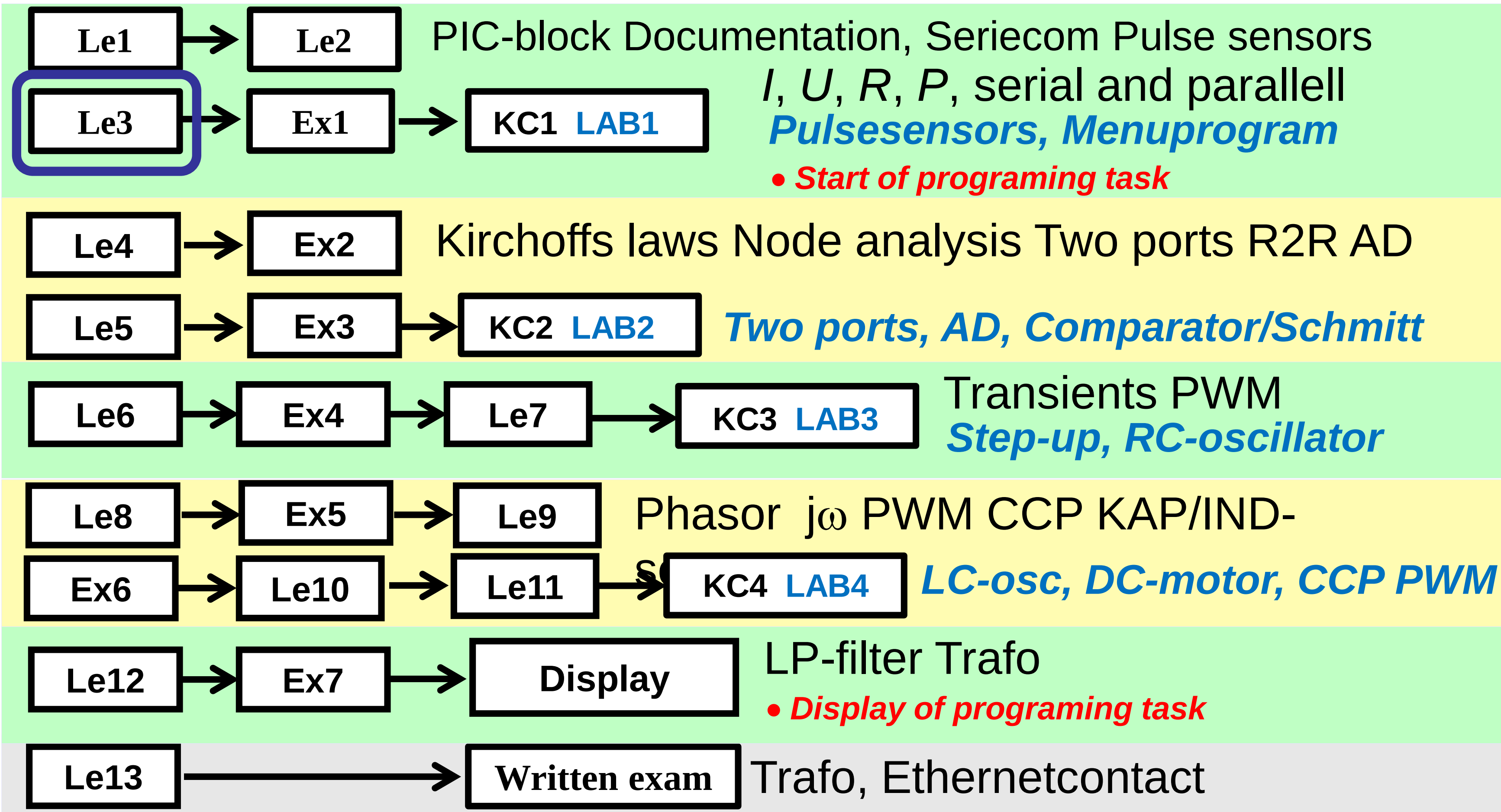
IE1206 Embedded Electronics



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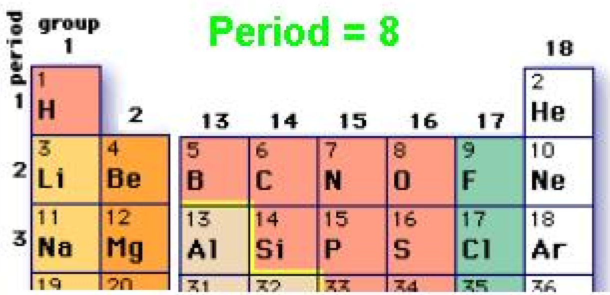
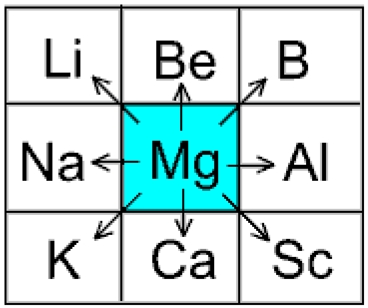
Mendeljev's discovery





1869 studied the Russian chemist Mendeleyev the then-known basic substances in order of their atomic weights. He found that similar material properties in general recurrence in subjects with distance eight steps in the atomic weight list. He therefore placed the elements in sequence in a "matrix" with 8 columns, rather than as a single weight list. This proved to be successful for many elements one could "predict" the physical and chemical properties by glancing at the neighbors'.

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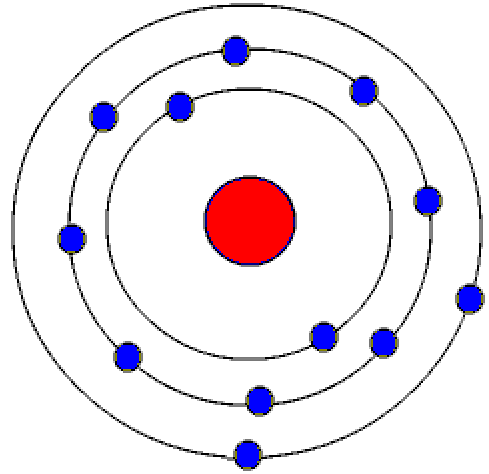
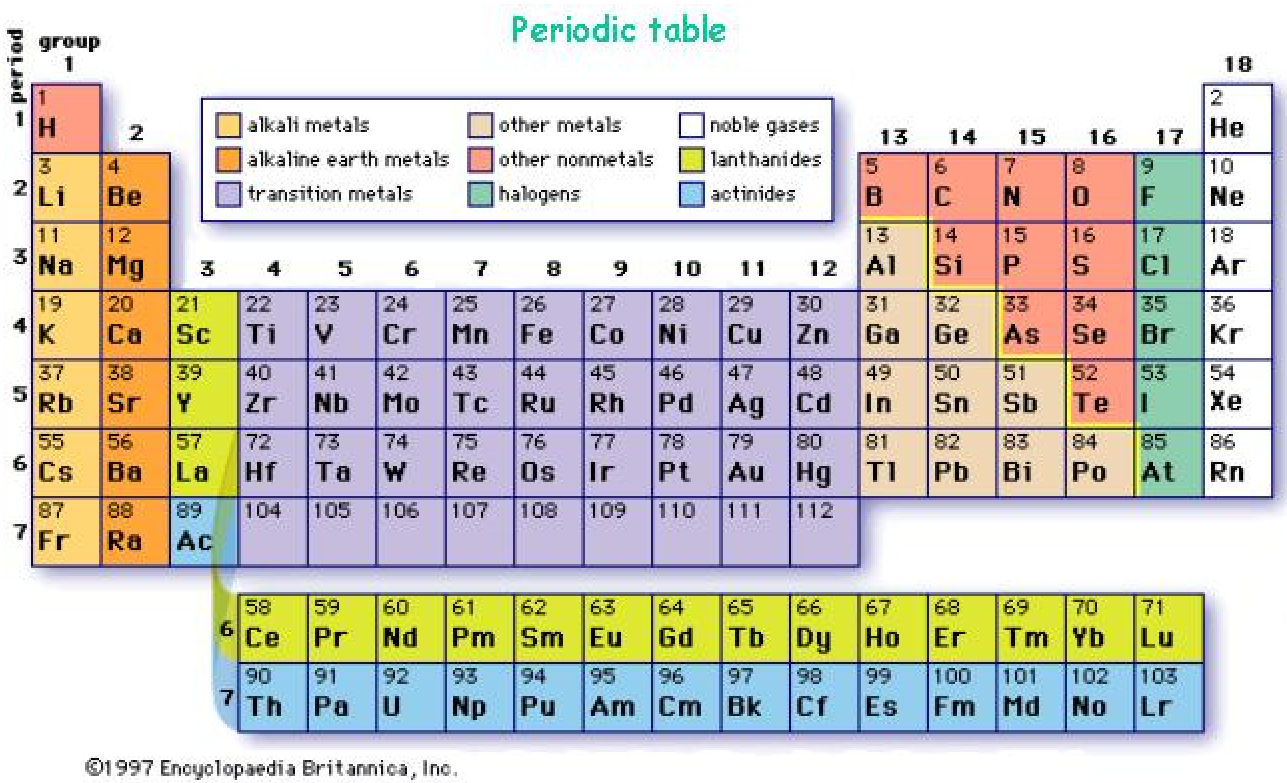
What is electricity



Example: School model of the Magnesium atom.
Magnesium by atomic number 12 has 12 protons in its nucleus that binds together with the help of 12 neutrons.
In paths around the nucleus 12 electrons circulates. The innermost shell is full and has two electrons, the next shell is full and has 8 electrons, the outermost known as the valence shell contains two electrons (with seating for 6 more, 8 in total).

Periodic system

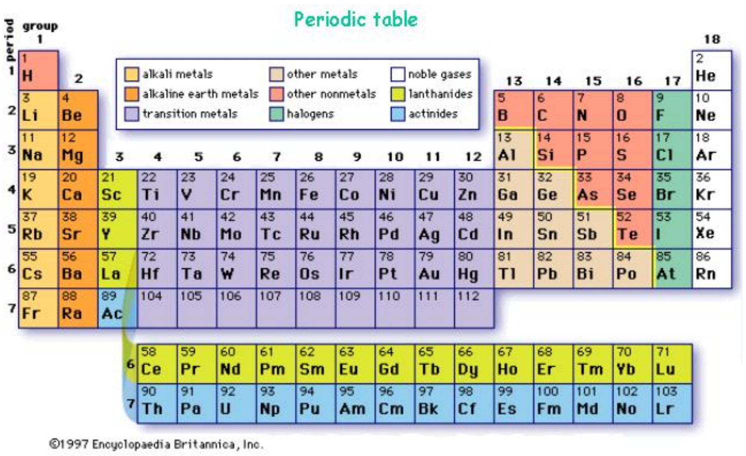


- Electricity is about charges, so even the elements electrical characteristics are determined by the valence electrons.

Leader/Insulator/Semiconductor

The elements are classified into metals and non-metals.

More than three-quarters of the elements are metals (while our globe is composed of 75% of non-metals).

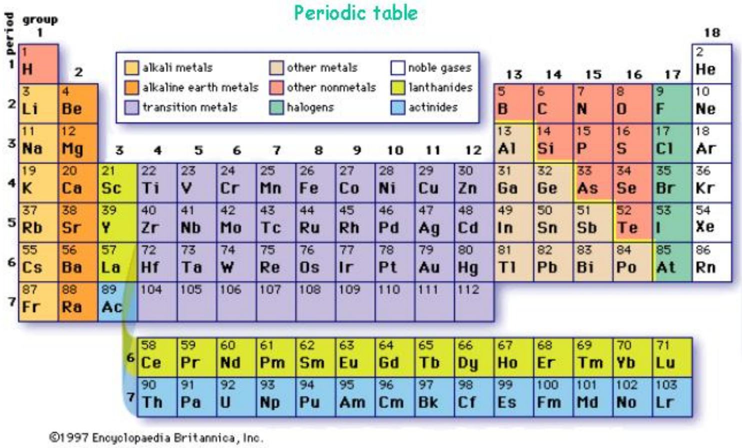


Metals have good ability to conduct electric current, they are leaders. They have at most half full valence shell (1 ... 5 valence electrons). The atomic electron shell forms a common "electron cloud".

Non-metals are insulators, that is, poor conductors of electric current. They have full, or nearly full, valence shell with tightly bound electrons.

Leader/Insulator/Semiconductor

Even ewlements with half-full valence shell can be insulators. There are crystalline materials in which the valence electrons are bound tightly to adjacent atoms. Carbon in the form of graphite is a conductive material, while the carbon in diamond is an insulator.



In the periodic table the metals are to left and non-metals to the right. In the area between metals and non-metals are semi-metals, which are electrically semiconductors. These materials have gained a great importance for electronics.

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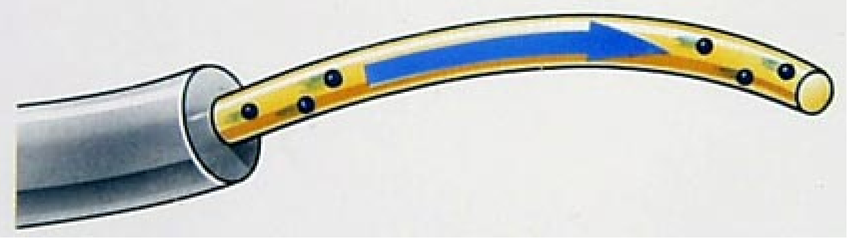
Voltage, current and resistance



An electric current is composed of the moving charges. A metal is containing free electrons that are constantly moving (due to thermal motion), but this is done randomly so no net currenet is generated.

If one adds charge, electrons, to one end of a metal wire the equilibrium will be disturbed and a stream of electrons will be flowing briefly in the thread. If you also can remove electrons from the the other end of the metal wire then a current will continue to flow through the wire.

Charge **Q** [As, Coulomb C]

The entity charge is denoted $\boldsymbol{Q}$. The unit of charge is called ampere-sekond [As], or coulomb [C].

How to Add/remove electrons?

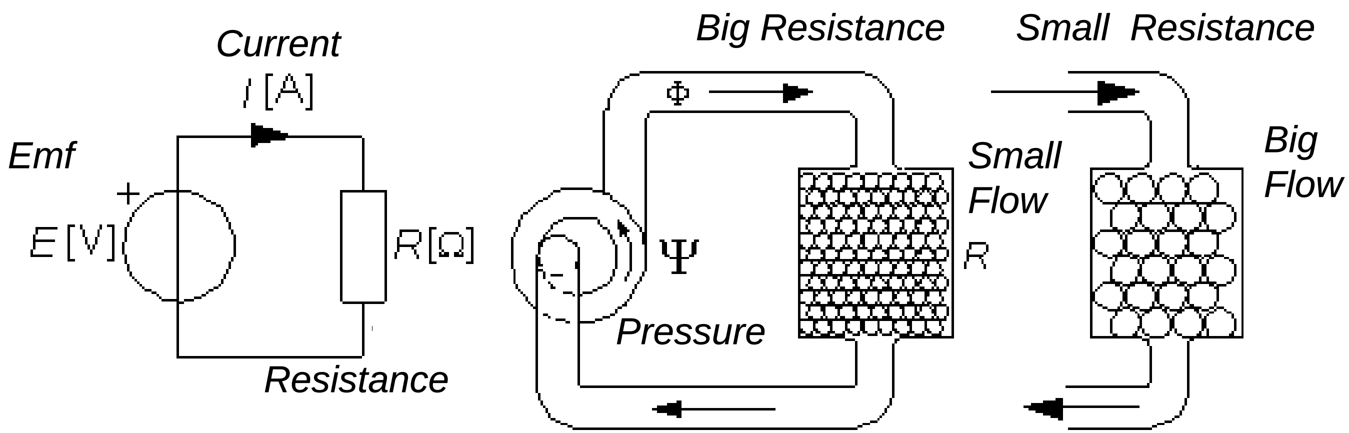
In a battery occurs electrochemical reactions that result in an excess of electrons at one electrode and a deficit at the other (more on this later). If the metal wire ends are connected to a battery's electrodes thus an electric current will flow through the wire.

The battery can be viewed as a "charge pump" which pumps electrons through the electrical circuit. The battery has, with an ancient word, an electromotive force **emf**.

The entity for emf is denoted with $\boldsymbol{E}$ (or with $\boldsymbol{U}$).
The unit of emf is Volt [V].

A fluid analogy

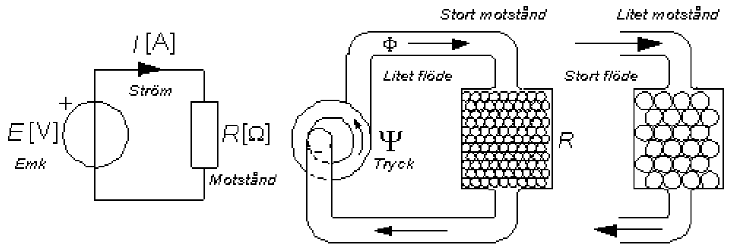
Many think that electrical engineering is abstract. It is therefore common to compare the abstract electrical circuits with more concrete fluid analogies. Emf (battery) can be likened to a water pump. The pump pressure difference between the inlet and outlet pipes Ψ corresponds to the emf voltage E.



The pump to circulates fluid through a filter. Fluid flow encounters obstacles or resistance along the way. If the filter is filled with "sand" the resistance becomes large and the pump pressure will only be enough to circulate a small liquid flow. If the filter is filled with gravel, the pressure will be enough to a greater flow.

A fluid analogy

For the electrical circuit the fluid-flow corresponds to the current of charged electrons.



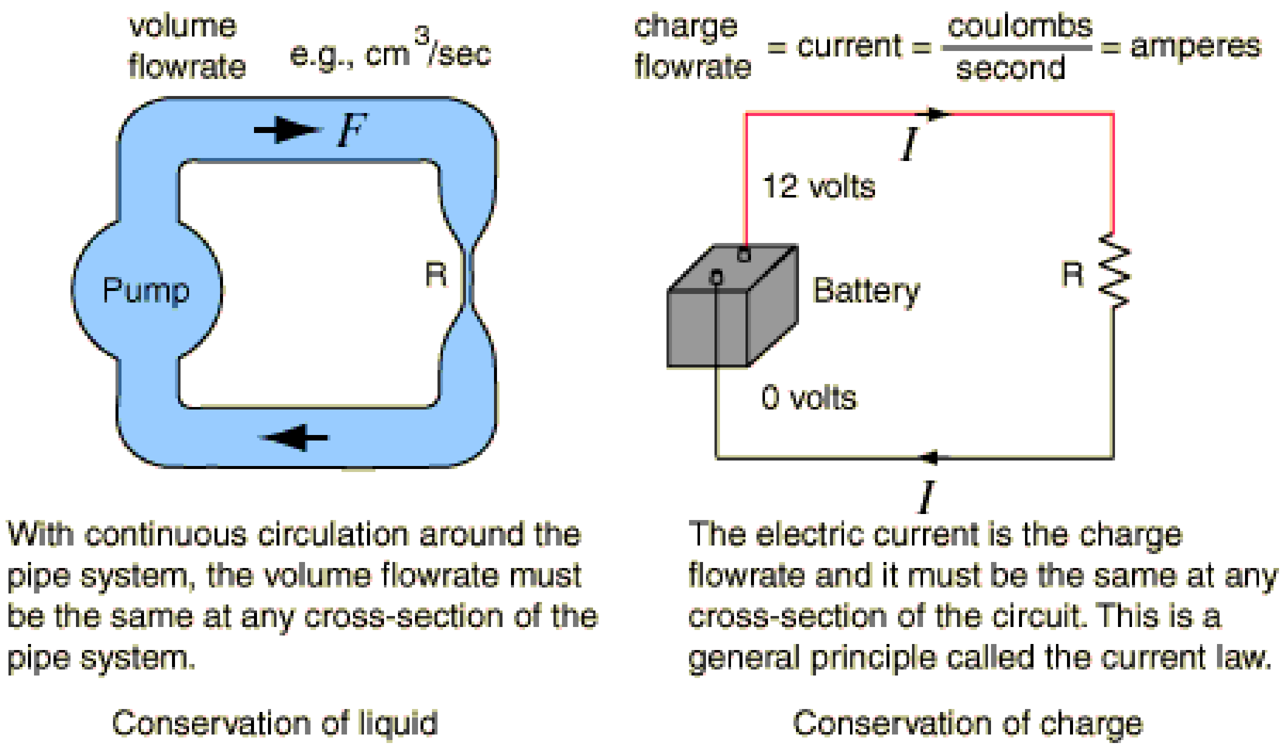
The entity for current is denoted ***I***. The unit for current is ampere [A].

The current *I* that the Emf *E* is able to push through the wire is material dependent. Materials with few free electrons have poorer conductivity, they have higher resistance, than those with more. When the electrons pass through the material the electrons sometimes collide with the atoms, and that gives rise to the resistance of the material.

The electrical resistance is denoted ***R***. The unit for resistance is Ohm **[Ω]**.

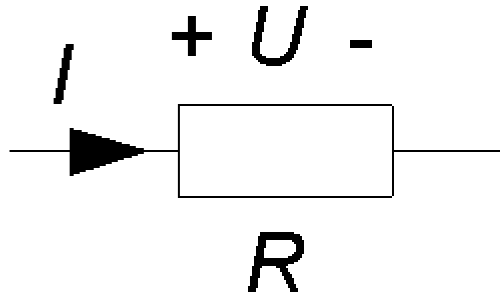
Fluid analogy to DC circuits

Fluid analogies are used by many authors.



[hyperphysics]()

Ohm’s Law



$$U = IR$$

The German physicist Simon Ohm formulated in 1826 the rule that is usually called **Ohms law**. If a current ***I*** passes trough a ledar with the resistance ***R*** so will there be a voltage drop by $\boldsymbol{U = I \times R}$. The voltage drop is proportional to both current and resistance.

With a liquid analogy, one can say that there is a "pressure drop" when the liquid flow passes a resistance.

American symbol for resistance

Do not confuse with the symbol of coil inductance, later introduced in the course.

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Plus and Minus

- One usually draw the voltage drop plus sign where the current enters the resistor.

This means that the current direction is from plus to minus - but is not this wrong? If the current is made up of electrons so should of course they be pulled toward the resistor positively charged end?

In Ohm's time they had no knowledge of elementary particles and simply "guessed" wrong - it is too late to correct this now, so everyone continues just as wrongly to this day ...

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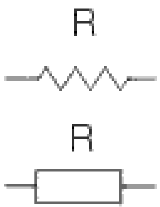
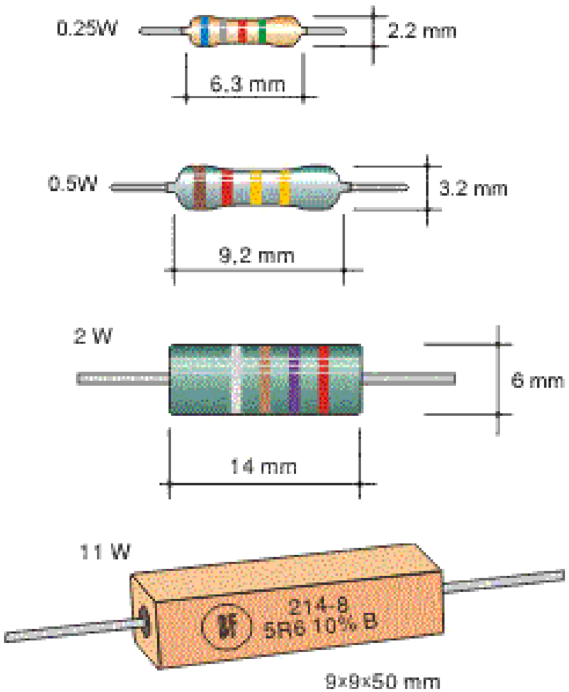
Resistors



Symbol



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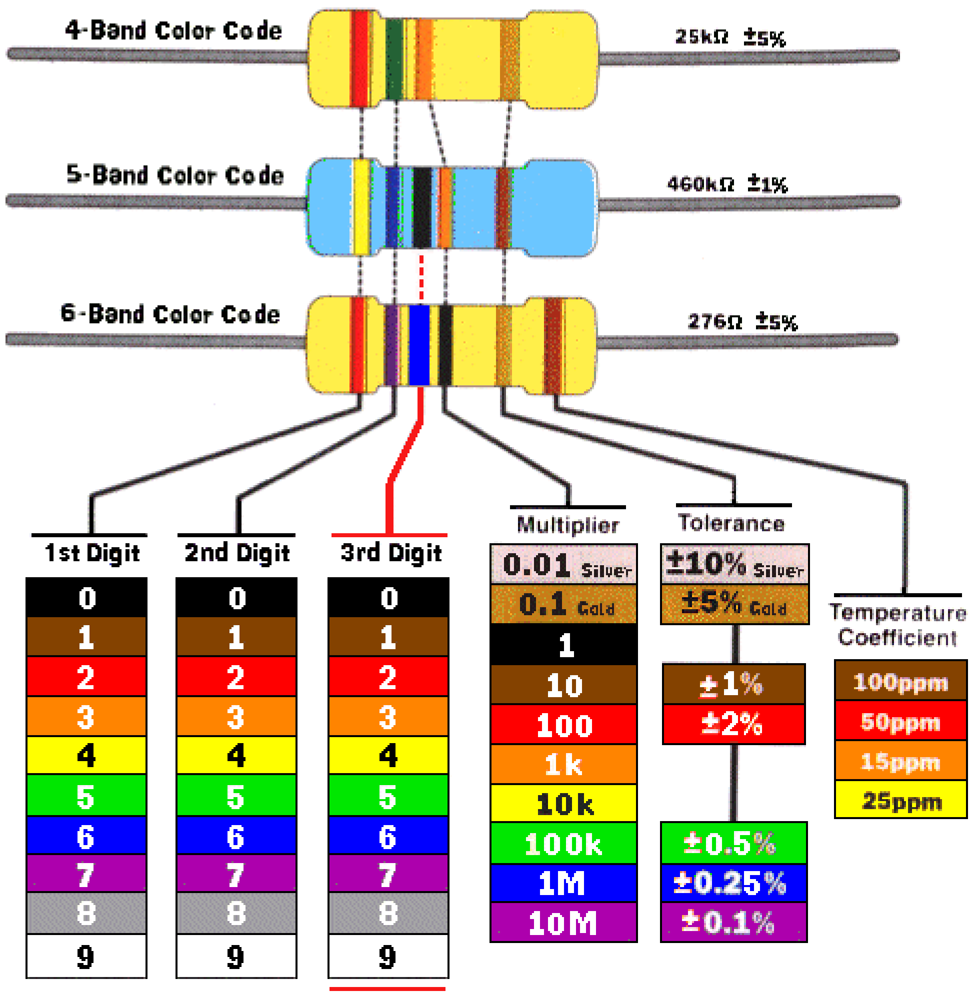
Resistor color code



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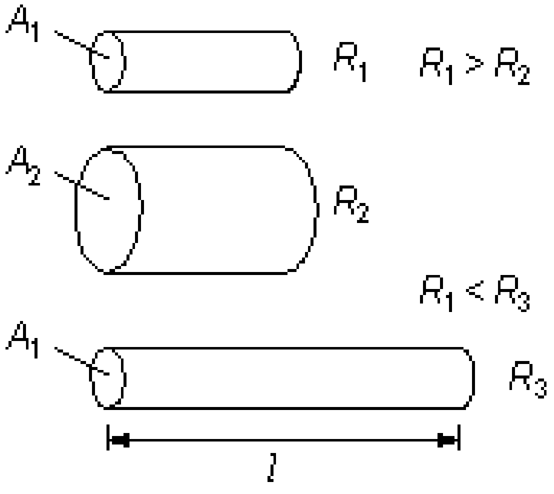
Conductor resistance

A conduction wire resistance depends on the number of free conduction electrons available for charge transport, ie what material it is made of, but also on the wire area ***A***. Since the conduction electrons encounter resistance along all the wire, so the resistance depends also on how long it is ***l***. The resistance is determined from the formula (it can also be good to know the formula for therelationship between area and diameter):

$$R = \rho \frac{l}{A} \qquad A = \pi \frac{D^2}{4}$$



Resistivity

$$R = \rho \frac{l}{A} \qquad A = \pi \frac{D^2}{4}$$

The material constant ρ in the resitance formula use is usually given as **[Ωmm²/m]**. This simplifies the calculations of cable resistances, as it is natural to talk about cable lengths in **[m]** and cross sectional areas in the order of **[mm²]** – but those who do not know this can be very puzzled!

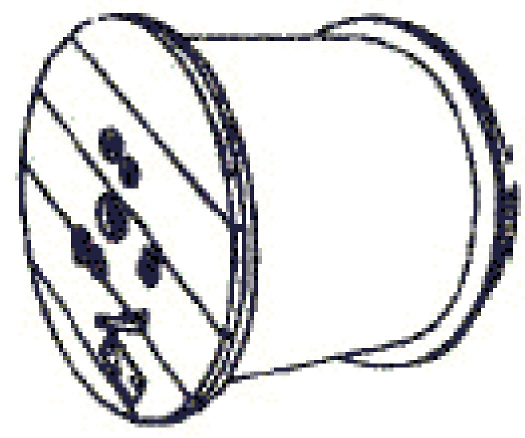
Metal	Resistivity ρ [$\Omega mm^2/m$]	Alloy	Resistivity ρ [$\Omega mm^2/m$]
Aluminum	0,027	Kanthal A	1,4
Gold	0,022	Konstantan	0,5
Iron	0,11	Manganin	0,43
Copper	0,018	Nichrom	1,1
Nickel	0,08	Nikrotal	1,09
Silver	0,016		
Wolfram	0,06		

Example – how long is the cable?

(Ex. 2.1) Example – how long is the cable?

An electrical installation company usually give their trainees following mission – in the store is a large and heavy cable on a reel, how long is the cable?

A cable consists of two conductors. A leader and a return conductor. The two leaders in the cable end that is wrapped in the back of the roll has been stripped and twisted together. The second cable end is directly accessible. On the cable reel side are stamped with the conductors cross-sectional area $\boldsymbol{A} = 2{,}5\ \text{mm}^2$.



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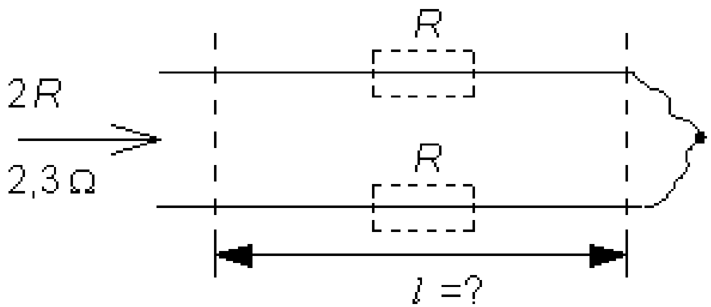
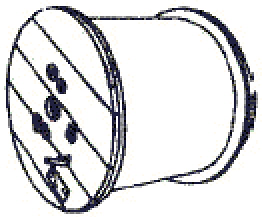
Example – how long is the cable?





A smart trainee go and get a Ω-meter and measures the resistance in the two series connected wires of the cable. This measurement gives $2R = 2{,}3\ \Omega$. Each wire then has the resistance $R = 1{,}15\ \Omega$.

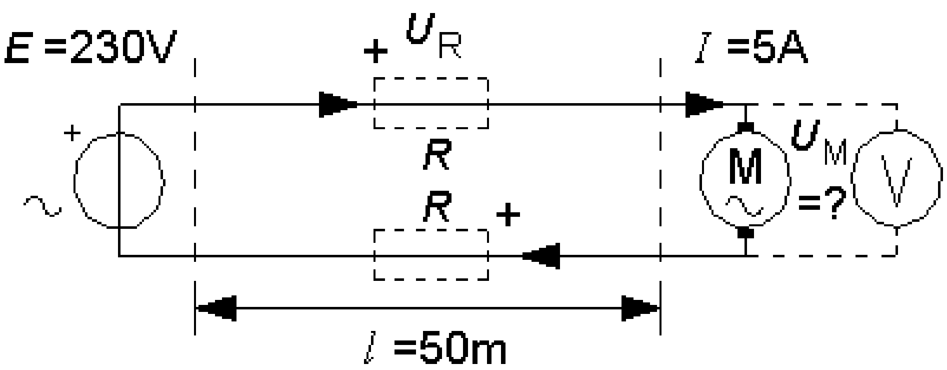
In the table one reads the resistivity of copper $\rho = 0{,}018$

The length l of the cable can be calculated :
$l = (R \times A) / \rho = 1{,}15 \times 2{,}5/0{,}018 = 159{,}7$ m

It had been troublesome to measure out the length of the cable with measuring tape! !

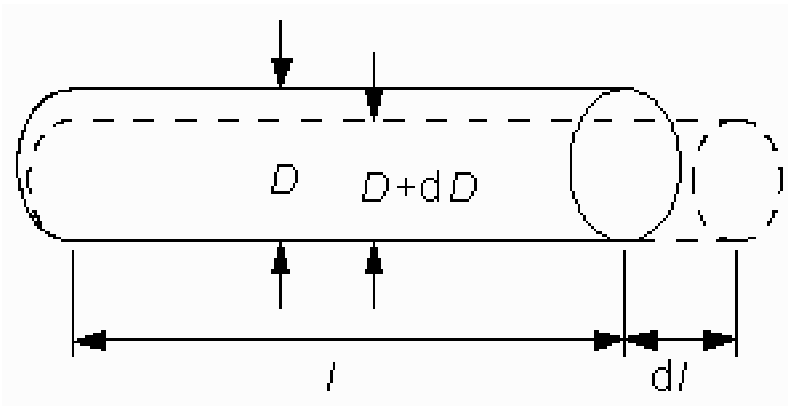
Example – Voltage drop in a cable

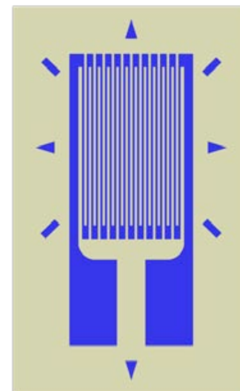
One uses a drill far away from a wall outlet with voltage $\boldsymbol{E}$ = 230 V. The The drilling machine draws the current $\boldsymbol{I}$ = 5 A and is connected with 50 m extension cord whose leaders have cross-sectional area $\boldsymbol{A}$ = 1,5 mm^2. How high will the voltage U_M at the drilling machine get?

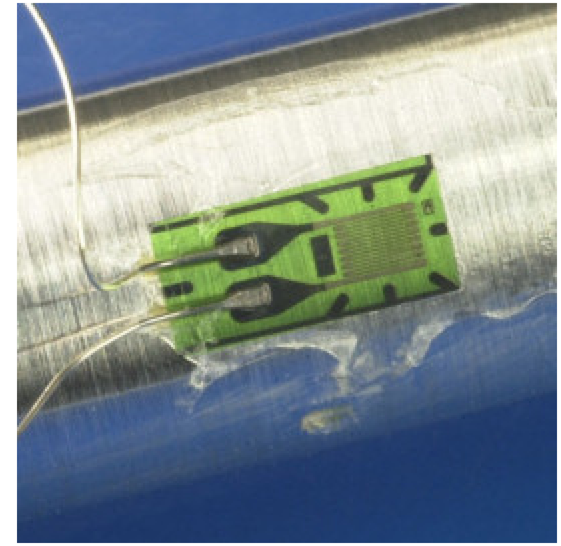


$R = (\rho \cdot l)/A = 0{,}018 \times 50/1{,}5 = 0{,}6\ \Omega$.
According to Ohm's law the current gives a voltage drop in the conductor $U_R = I \times R = 5 \times 0{,}6 = 3$ V, and a equally big voltage drop in the return conductor.
We get: $E - I \times R - U_M - I \times R = 0$. $U_M = 230 - 2 \times 3 = 224$ V.

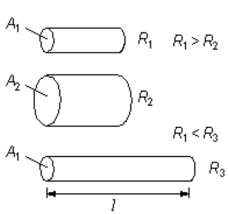
Example - strain gauge







Strain measurement. A wire is glued on a surface that is exposed to forces and therefore stretched. The wire is then stretched to, and become "longer" and "tighter" so the resistance increases. ΔR is proportional to the strain ε.
The stresses building structures and machine constructions are exposed to can be measured using strain gauges.



$$R = \rho \frac{l \cdot 4}{D^2 \cdot \pi} \qquad \varepsilon = \frac{\Delta l}{l} \quad \Rightarrow \quad \Delta R \approx k \cdot \Delta l$$

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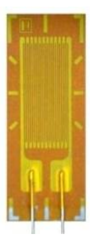
Example - strain gauge

”Slussen” in Stockholm is damaged - strain gauges are used to alert if the deformations would be critical.



A microprocessor is of course also included.

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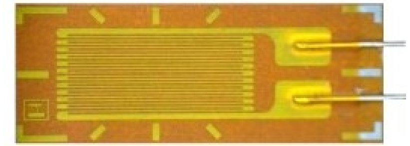
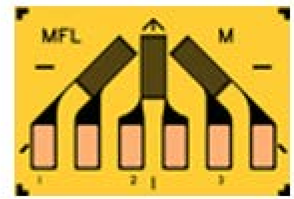
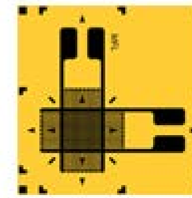
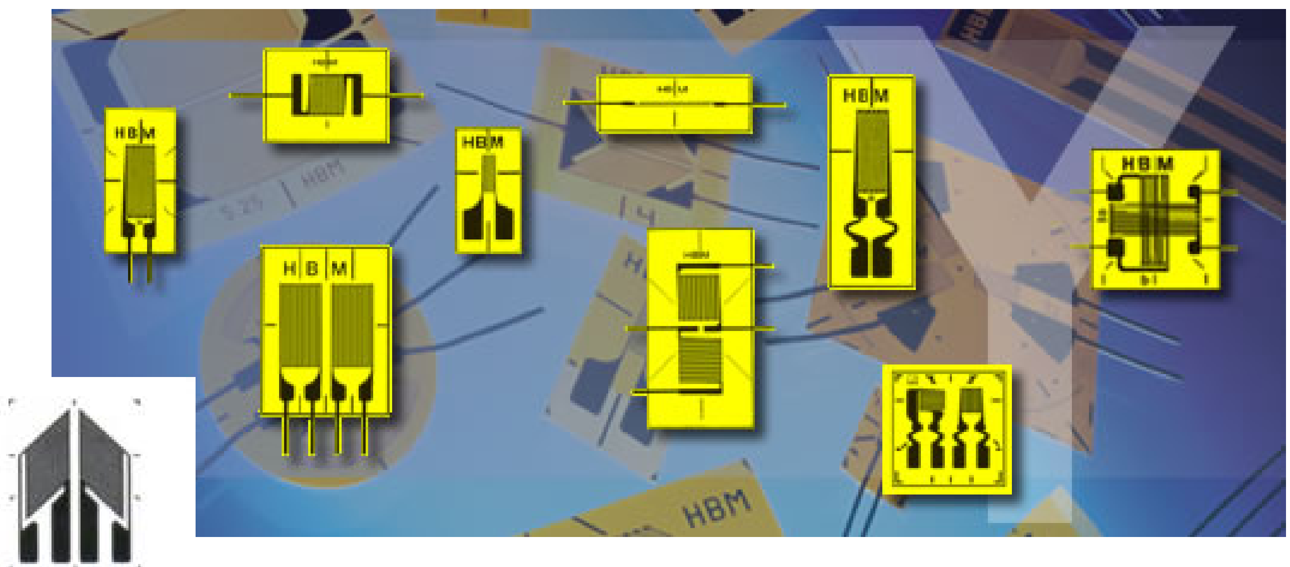
Strain gauges of different types









Resistance temperature dependence

If you heat a metal wire the resistance increases. This is because the atomic thermal motion increases, and then there are more electrons colliding with the atoms along the wire. The temperature effect is significant. The resistance may be doubled before reaching the metal's melting point!

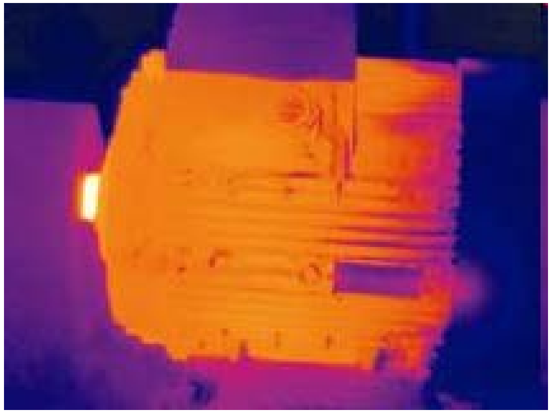
Metal	**temp.coeff α**	**Metal**	**temp.coeff α**	**Alloy**	**temp.coeff α**
Aluminum	$4{,}3 \cdot 10^{-3}$	Nickel	$6{,}7 \cdot 10^{-3}$	Kanthal A	$49 \cdot 10^{-6}$
Gold	$4 \cdot 10^{-3}$	**Copper**	$3{,}9 \cdot 10^{-3}$	Konstantan	$\pm 50 \cdot 10^{-6}$
Platina	$3{,}8 \cdot 10^{-3}$	Wolfram	$4{,}5 \cdot 10^{-3}$	Manganin	$\pm 2{,}5 \cdot 10^{-6}$

For a resistor having the resistance R_1 at temperature t_1, and the resistance R_2 at temperature t_2 follow this linear relationship:

$$\Delta t = t_2 - t_1 \qquad R_2 = R_1 \cdot (1 + \alpha \cdot \Delta t)$$

Ex. – What temperature has the motor winding?

If an electric motor is loaded to hard, the power loss may become so high and the electrical windings become heated so that the insulating material is liable to melt. Motor winding will be shorted, and the engine becomes unusable.



IR-picture of a electric motor with a to hard load!

Suppose you have an electric motor with a winding that is insulated with a material that can withstand the temperature **110°C**. One are not sure if there is a risk of overloading the motor, so it is planned to measure temperturen in the winding.

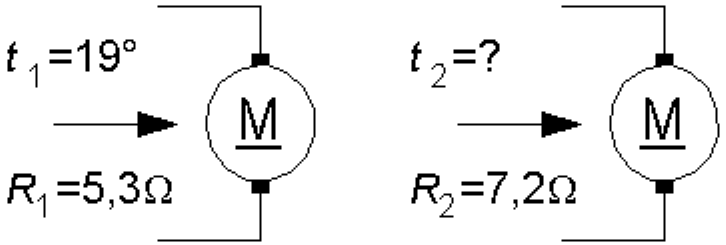
How to place a thermometer inside the (rotating) winding?

Temperature measurement in the motor winding

Hint! The winding of copper wire can it self be the thermometer!

When the engine rested one measures the room temperature to 19°.
Motor winding then has this temperature, t_1 = 19.
Then the resistance of the motor winding is measured R_1 = 5,3 Ω.
The motor is then run under heavy load. One stops the engine and measures the winding resistance again R_2 = 7,2 Ω.
Is the engine temperature now so high that it is close to overloading?

$t_2 = ?$



The winding is of copper with the temperature coefficient $\alpha = 3{,}9 \times 10^{-3}$.

$\Delta t = (R_2 - R_1) / (R_1 \times \alpha) = (7{,}2 - 5{,}3) / (5{,}3 \times 3{,}9 \times 10^{-3}) = 91{,}9$°C.
$t_2 = t_1 + \Delta t = 19 + 91{,}9 = 110{,}9$°C *Ooops! Ooops!*

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Temperature

Temperature affects virtually **all** physical phenomena - even when you are not primarily interested in measuring the temperature, one must often still measure it in order to correct for its impact on other variables!

ITS-90

International Temperature Scale ITS-90

17 fixtemperatures for transitions between solid/liquid/gas form.

(*The transitions requires that one supplies/carries away great amounts of energy - the temperature then becomes constant as long as the state transition is in progress*).

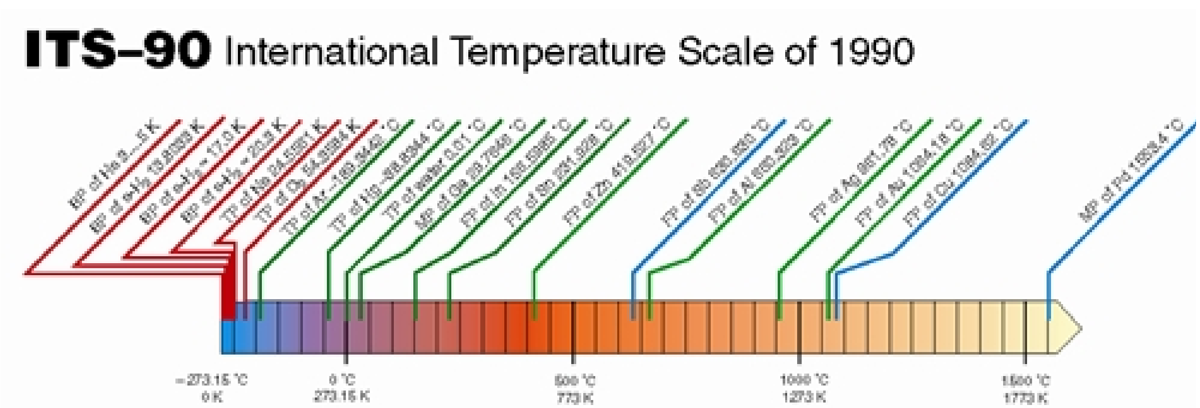
	Temperature			
Number	T_{90}/K	t_{90}/°C	Substance[a]	State[b]
1	3 to 5	-270.15 to -268.15	He	V
2	13.8033	-259.3467	e-H_2	T
3	~17	~-256.15	e-H_2 (or He)	V (or G)
4	~20.3	~-252.85	e-H_2 (or He)	V (or G)
5	24.5561	-248.5939	Ne	T
6	54.3584	-218.7916	O_2	T
7	83.8058	-189.3442	Ar	T
8	234.3156	-38.8344	Hg	T
9	273.16	0.01	H_2O	T
10	302.9146	29.7646	Ga	M
11	429.7485	156.5985	In	F
12	505.078	231.928	Sn	F
13	692.677	419.527	Zn	F
14	933.473	660.323	Al	F
15	1234.93	961.78	Ag	F
16	1337.33	1064.18	Au	F
17	1357.77	1084.62	Cu	F

- Water tripple point 0,01 °C

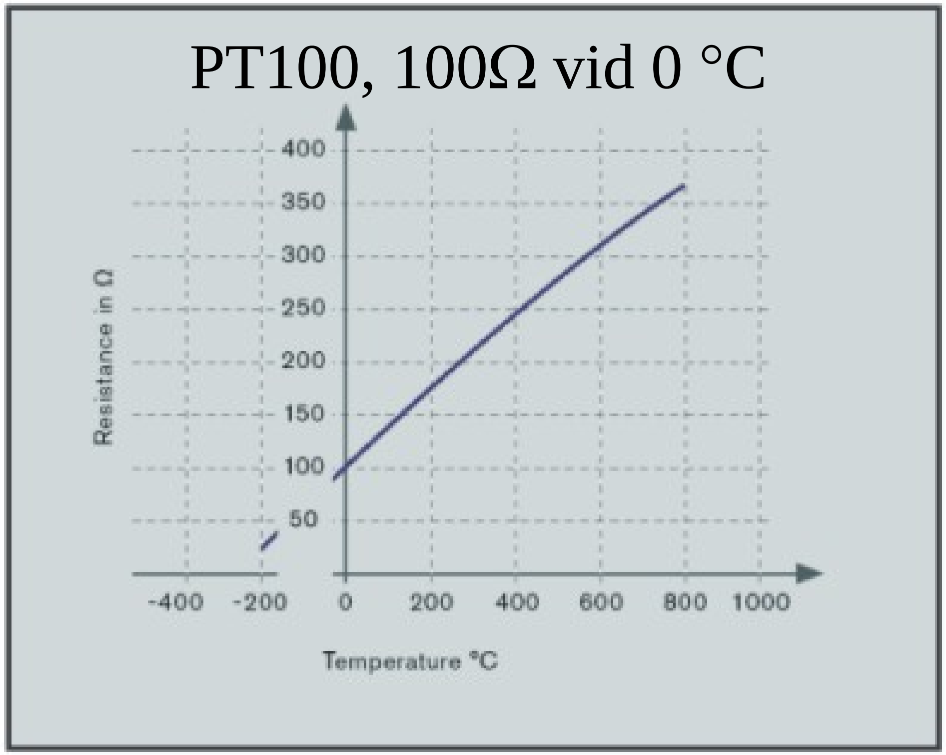
Temperatures between the fixpoints

Between fix points you use resistance thermometer (or at very high temperatures pyrometer).

In general, one buys a temperature sensor with the data specified by international standards.



Resistance thermometers



Materialkonstanter för resistiva givarelement

Material	a [/°C]	b [(/°C)^2]	α [/°C] (0…100 °C)
Pt (0…600 °C)	$+3{,}911\cdot10^{-3}$	$-0{,}588\cdot10^{-6}$	$+3{,}850\cdot10^{-3}$
Ni (0…200 °C)	$+5{,}43\cdot10^{-3}$	$+7{,}85\cdot10^{-6}$	$+6{,}17\cdot10^{-3}$

Resistive temperature sensors. Platinum, nickel (Copper - USA)

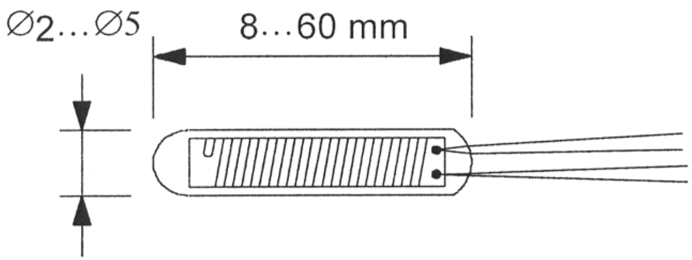
$$R = R_0(1 + a\cdot\vartheta + b\cdot\vartheta^2)$$

Linear approximation:

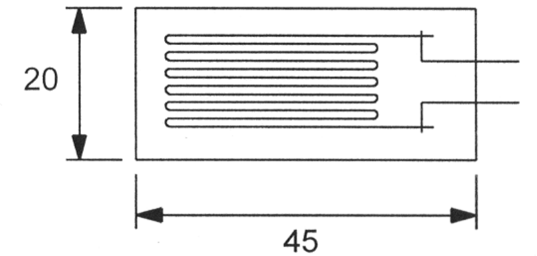
$$\boxed{R = R_0(1 + \alpha\cdot\vartheta)}$$

$$R_0 = 100\ \Omega$$

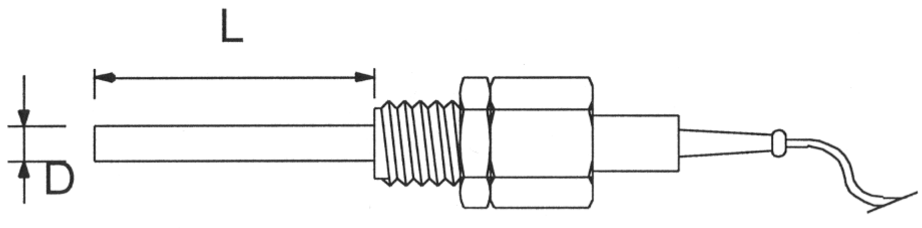
Temperature sensors - measuring resistors



measuring resistor embedded in hard glass. The resistance is equipped with four test leads



surface probe consisting of a nickel loop on glass foil



Sensor for measuring temperature in pipelines and storage tanks

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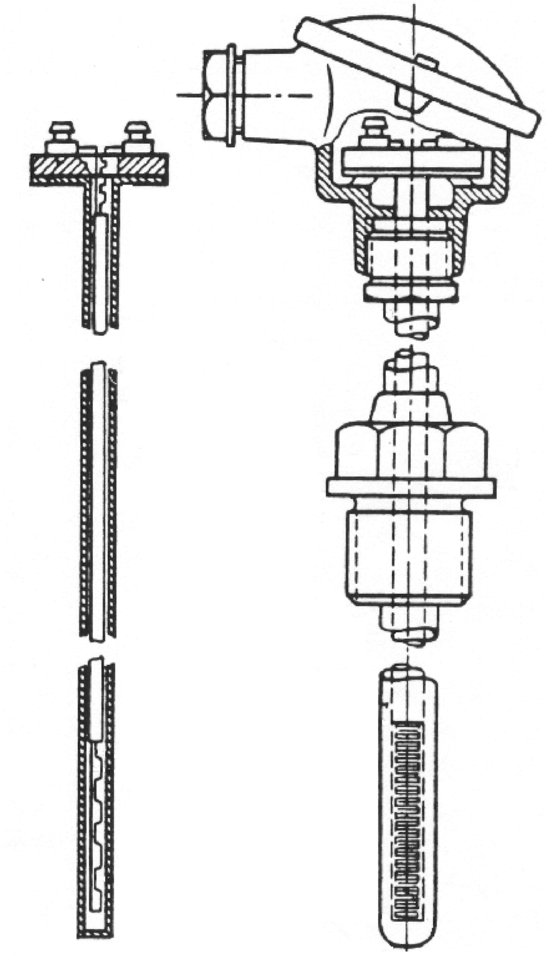
For process industry



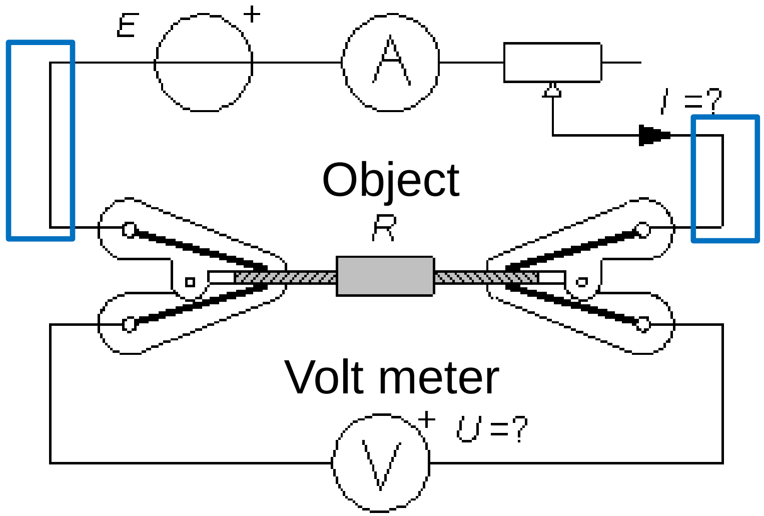
Resistance measuring, Four wire measurement

Voltage source

Current meter

Set the measure current

This voltage drop will not be seen by the voltmeter!

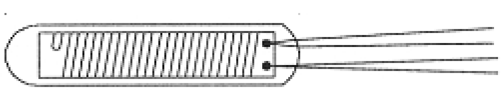


Object

Volt meter

Kelvin-clips

$$R = \frac{U}{I}$$



So, thats the reson for the measuring resistor to have *four* test leads!

Resistance thermometer

Resistance thermometers generally has of resistance wire platinum and the value100 Ω at 0°C (PT-100). The relationship between resistance and temperature is close to linear.

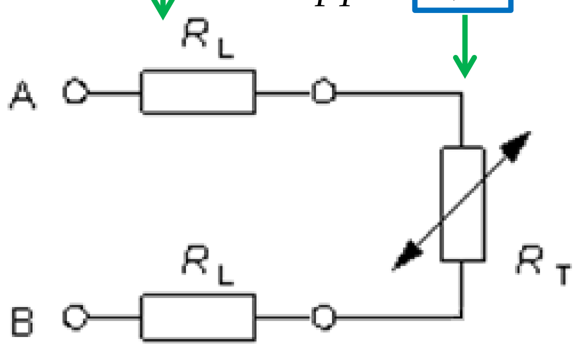
- One problem is that the connection cable with copper conductors are **equaly temperature sensitive** as theplatinum resistor!

$$R_T = 100(1 + 3{,}85 \cdot 10^{-3} \cdot t) \quad [\Omega]$$

$$\alpha_{CU} = \boxed{3{,}9} \cdot 10^{-3}$$

$$\alpha_{PT} = \boxed{3{,}8} \cdot 10^{-3}$$

Close!



Where does the thermometer end - and were does the connecting line begin?
A long cable, lying in the sun, are adding several "temperature dependending" OHMs to the resistance thermometer value!

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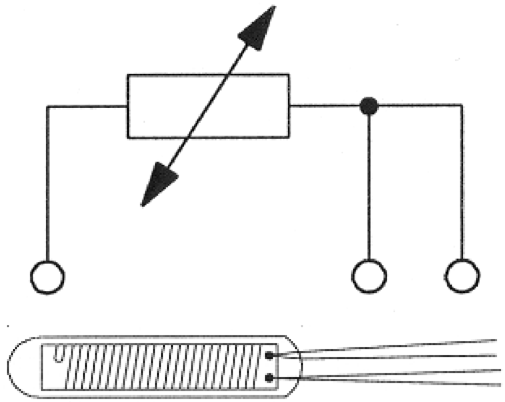
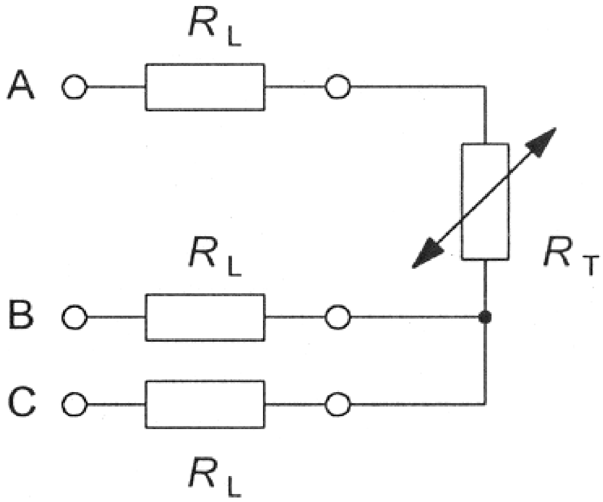
Three wire connection (ex. 2.4)



One of the four test leads is unused at *three* wire connection



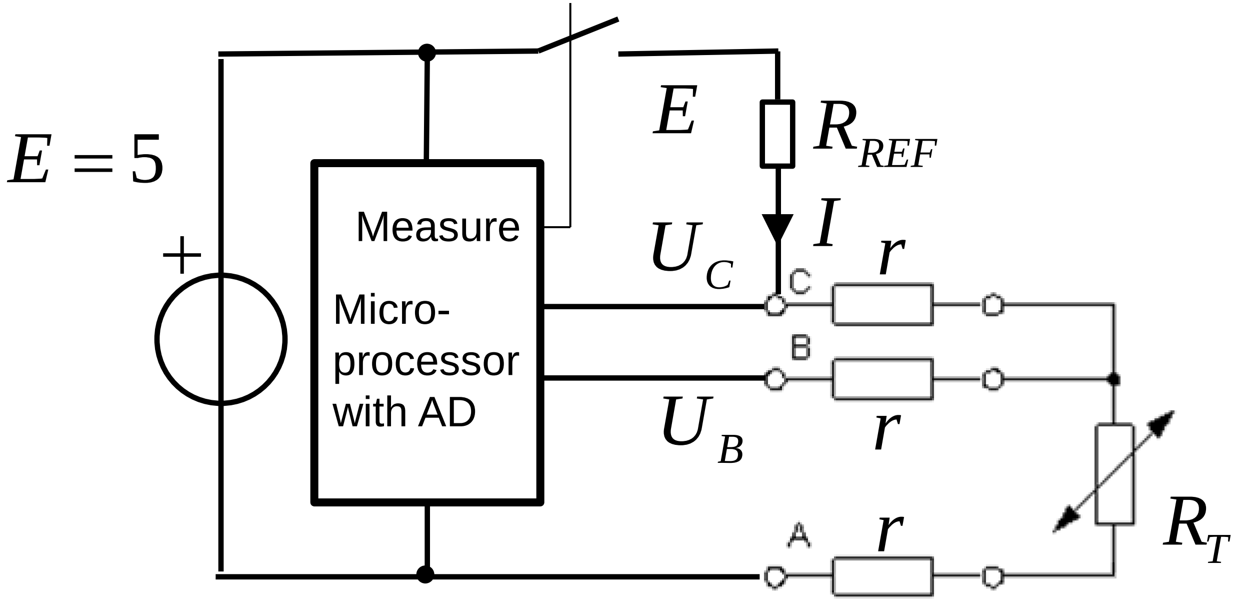
Three wire connection:

- Measure resistance between A and B $(R_{AB} = R_T + 2R_L)$
- Measure resistance between B and C $(R_{BC} = 2R_L)$

Calculate the searched resistance as: $R_T = R_{AB} - R_{BC}$

(Measure with AD-converter)

- The resistance thermometer is only switched on briefly before each measurement, not to heat up the thermometer with the measurement current I !



Measure U_C and U_B. Calculate R_T !

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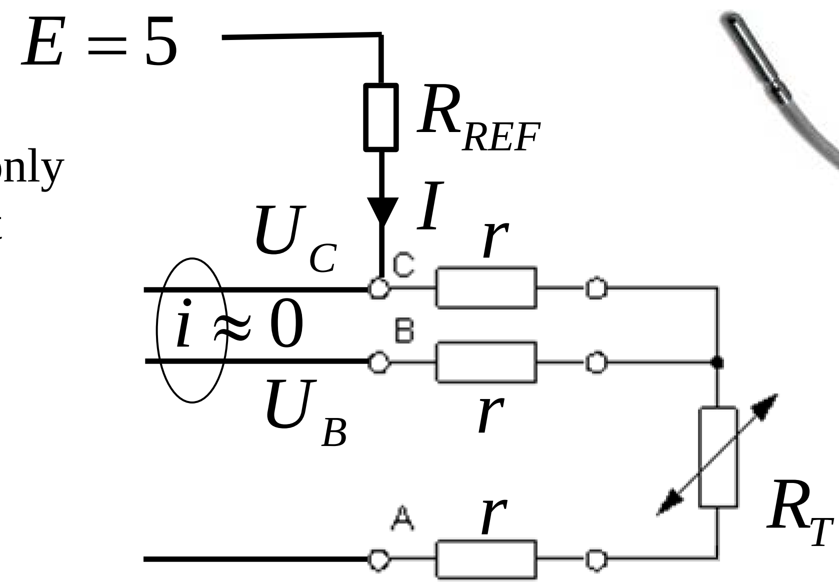
Measure with AD-converter

ADC inputs draw only a negligible current from the measured object ($i \approx 0$).



- With this course you will be able to produce useful expressions:

$$I = \frac{E - U_C}{R_{REF}} \quad r = \frac{U_C - U_B}{I} \quad R_T = \frac{U_C}{I} - 2r \quad \Rightarrow \quad \boxed{R_T = \frac{2U_B - U_C}{E - U_C} \cdot R_{REF}}$$

Numbers: $E = 5\text{V}$ $R_{\text{REF}} = 100\Omega$ $U_{\text{C}} = 3{,}34\text{V}$ $U_{\text{B}} = 3{,}30\text{V}$ $R_{\text{T}} = 196{,}3\Omega$ $r = 2{,}5\Omega$ $\boxed{t = 250°}$

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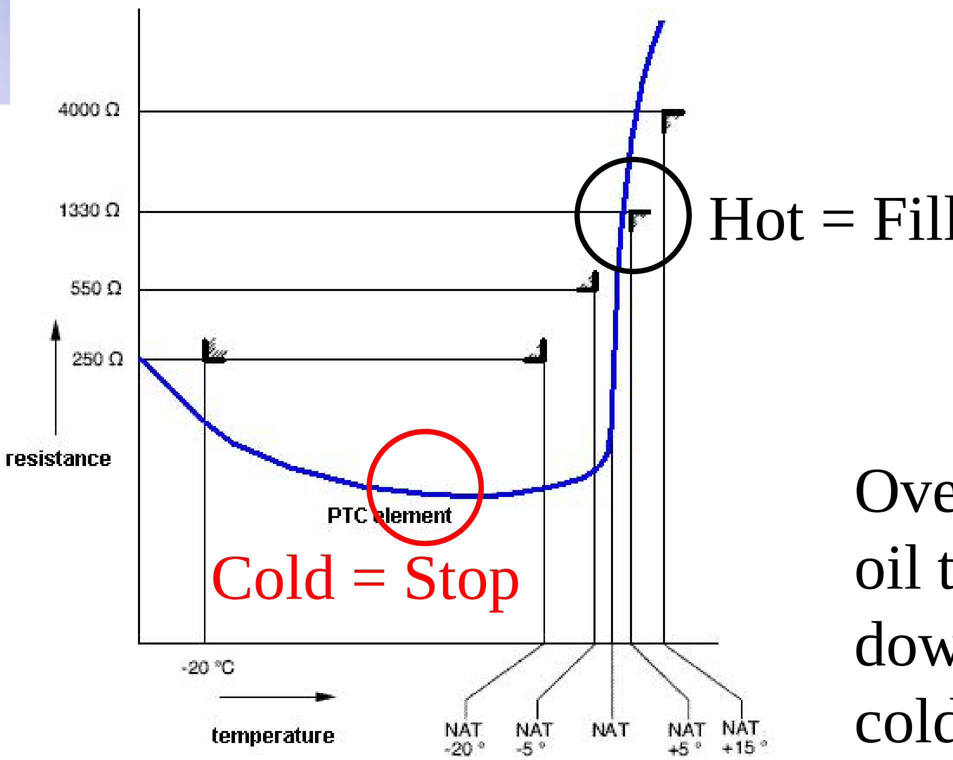
(PTC – thermistors)

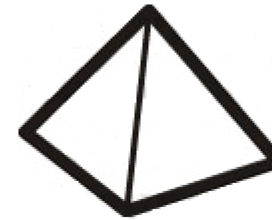


Overfill protection for the oil tank. When the sensor is down in the oil it becomes cold despite the heating current.

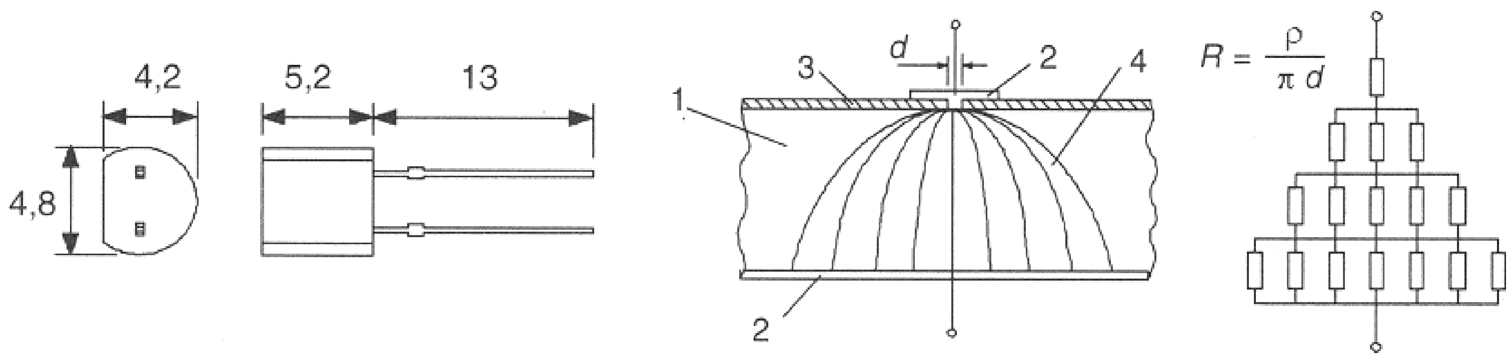
PTC thermistors are **highly nonlinear** and is therefore not suitable as thermometers, but only as alarm sensors.

Pyramids are magic!

Si-PTC thermistor



Semiconductor devices are made of silicon, and a **low-cost option** may be to make a resistance thermometers of this material. But how can a semiconductor resistor be manufactured with a tight tolerance?



Under a round connector with a diameter *d* a pyramid-shaped spreading resistance is formed. That resistance value will only be determined by *d* and the resistivity of the material ρ.
Both these factors could semiconductor manufacturers master.

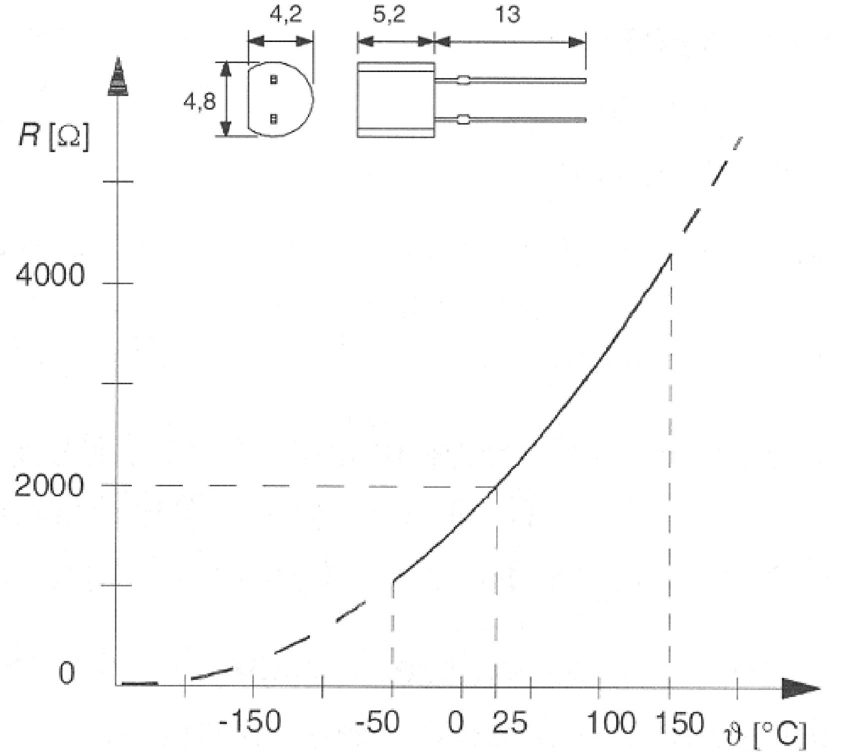
Si-PTC thermistor

$$R = R_0 + k(\vartheta - \vartheta_0)^2$$

$$R_0 = 16\,\Omega \quad \vartheta_0 = -241{,}5\,°\mathrm{C}$$

$$k = 2{,}79 \cdot 10^{-2}\ \Omega / °\mathrm{C}^2$$

The sensor has a simple mathematical temperature relationship. Linearization can therefore be in the software.

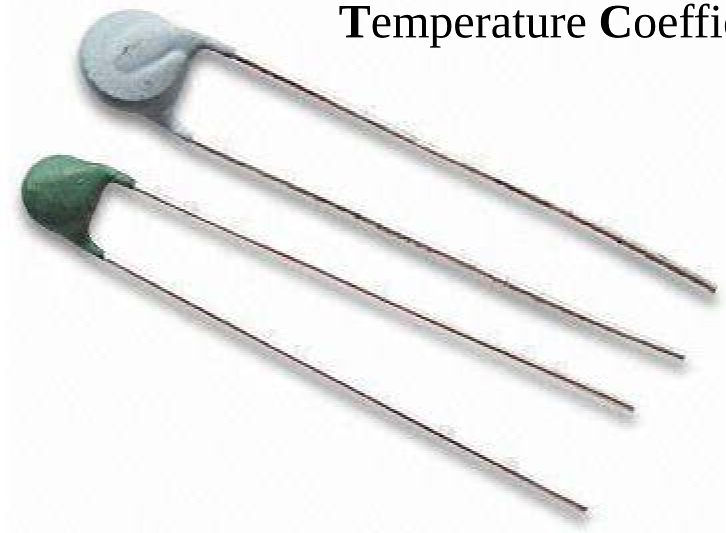


A common value at 25°C is R_{25} = 2000 Ω.

NTC Thermistor

Resistors of metal oxides are very temperature sensitive.

The resistance decreases with increasing temperature so the temperature coefficient is negative. (**N**egative **T**emperature **C**oefficient)

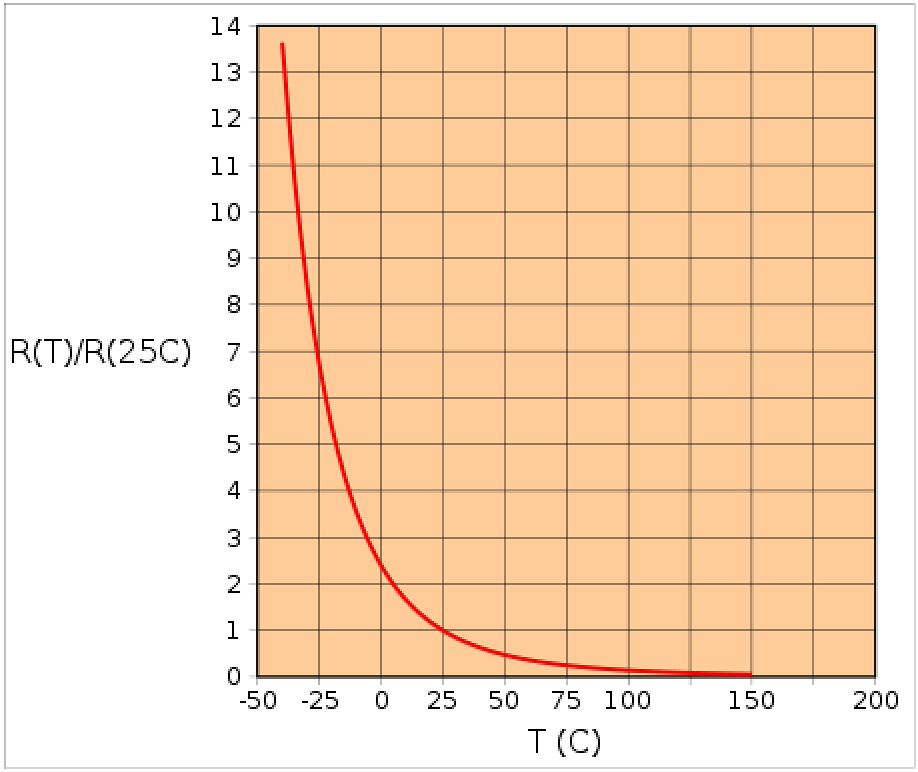


NTC Thermistor

NTC thermistors are often used for temperature measurement.

The relationship between resistance and temperature is highly non-linear (= exponential).

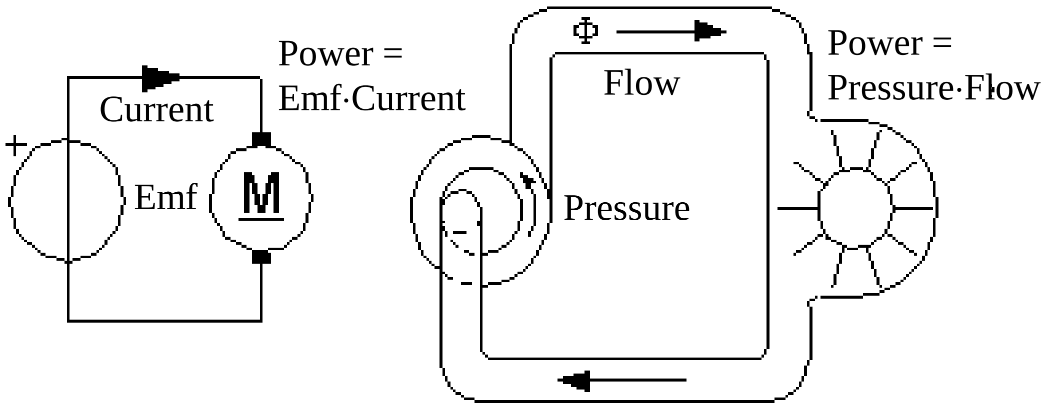
However, there are simple methods to linearize the relationship, and NTC thermistors is therefore very commonly used as temperature sensors.



NTC-thermistors. All possible (*and impossible*) *embodiments are available!*

Electrical power

A water pump can perform work by pumping up water. Work is the force times distance [Nm] and Power *P* is work per time [Nm/s, W].
If the pump operates on a water wheel we get the power as the product of pressure and fluid flow: $\boldsymbol{P}$ [Nm/s, W] = $\boldsymbol{\Psi}$ [N/m^2]×$\boldsymbol{\Phi}$ [m^3/s].

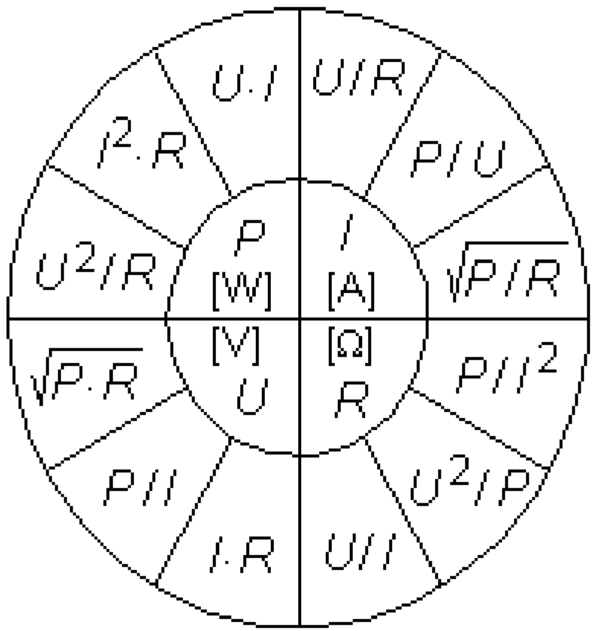


The electric current can also perform work. Here the power is the product of voltage and current: $\boldsymbol{P} = \boldsymbol{U}$ [V]×$\boldsymbol{I}$ [A]

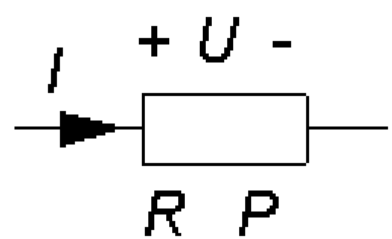
The entity for power is denoted $\boldsymbol{P}$. The unit for power is Watt **[W].**

U, I, R, P

The expression for the electric power can be combined with Ohm's law. You then get a variety of useful expressions. Often, these are presented in the form of a circle.



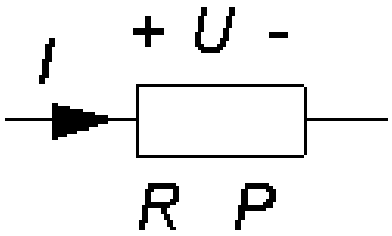
- 12 useful expressions!



A current passes trough a resistor
In the center we read *U I R* and *P*
In the tvelve sectors are the expressions
with the relationships between the quantities.

Rated Power

$$P = I^2 \cdot R \qquad P = \frac{U^2}{R}$$



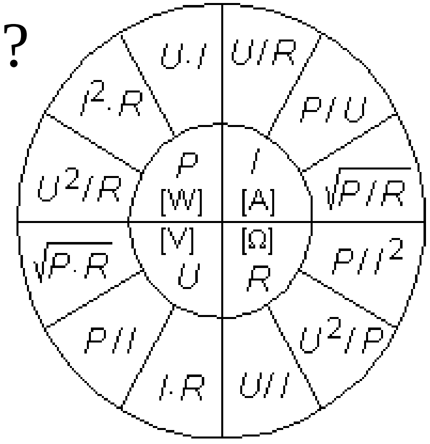
A power resistor with the resistance **150 Ω** has the rated power **3W**.

a) How ***big current*** can the resistor handle?

$$P = I^2 \cdot R \quad \Rightarrow \quad I = \sqrt{\frac{P}{R}} = \sqrt{\frac{3}{150}} = 0{,}14\ \text{A}$$

b) How ***big voltage*** can the resistor be connected to?

$$P = \frac{U^2}{R} \quad \Rightarrow \quad U = \sqrt{P \cdot R} = \sqrt{3 \cdot 150} = 21\,\text{V}$$



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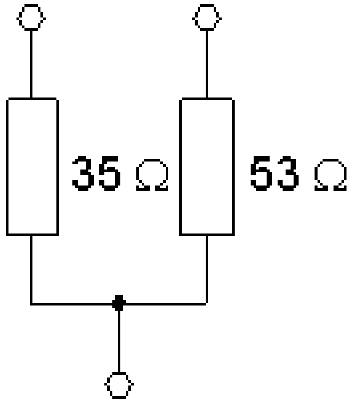
Example – Power, hotplate



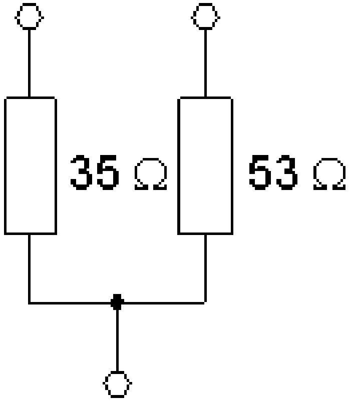
For those who would rather replace a broken hob than the entire cooker there are loose spare hobs to buy. The hotplate includes two heating coils (= resistors) with different resistance values. Connections to the heating coils is done with three pins. Cooking hob control is a switch that connects the coils in various ways, so that four evenly spaced power settings are obtained.

Power, hotplate

$$P = \frac{U^2}{R}$$

A hotplate with resistances 35 Ω and 53 Ω is connected to 230 V mains.
Calculate power P_{35}, P_{53}, P_{35+53} (series connection), $P_{35//53}$ (parallel connection).

Rank the effects in ascending order. Here it is appropriate to use the power formula: $P = U^2/R$



$P_{35+53} = 230^2/(35+53) = 600$ W
$P_{53} = 230^2/53 = 1000$ W
$P_{35} = 230^2/35 = 1500$ W
$35//53 = 35 \times 53/(35+53) = 21$
$P_{35//53} = 230^2/21 = 2520$ W

- *Will the four power modes be evenly distributed?*

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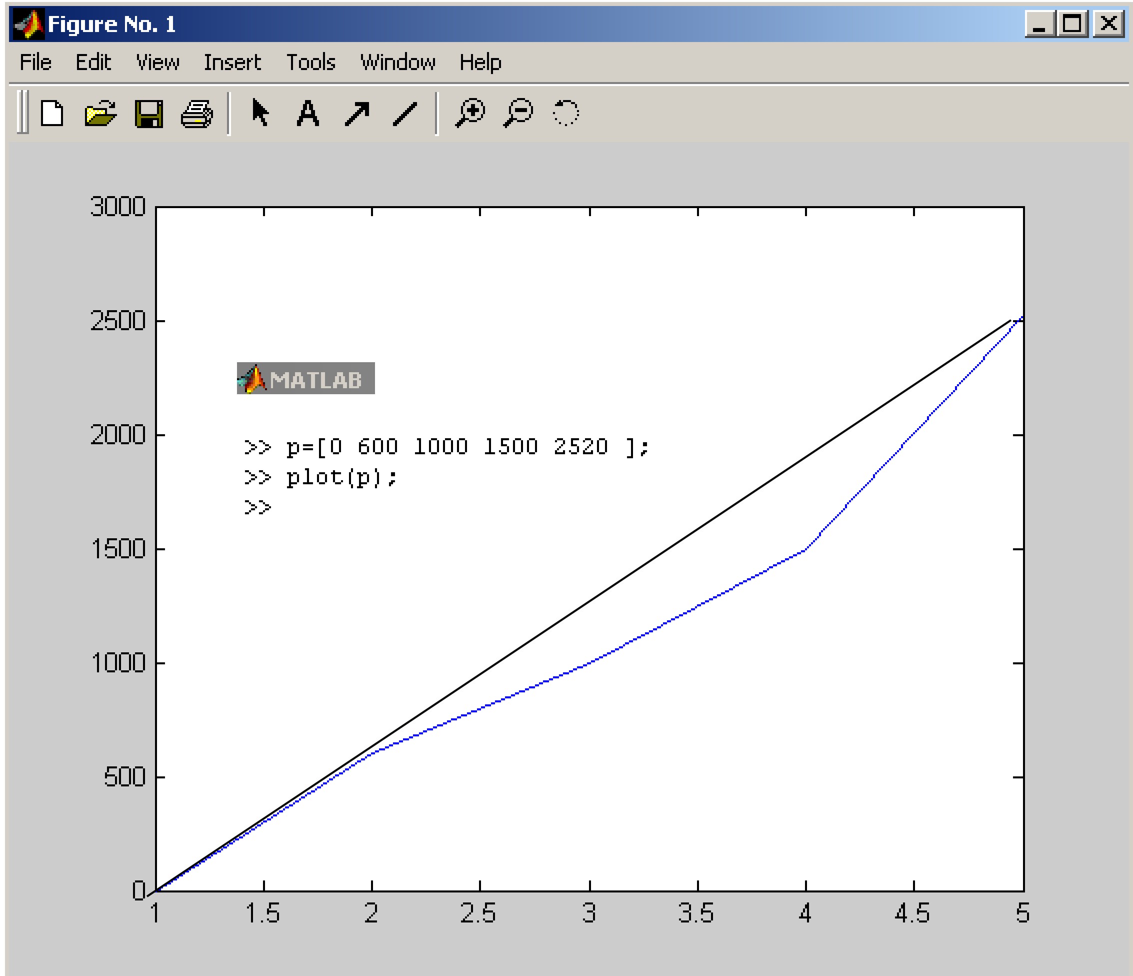
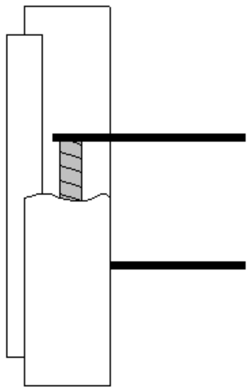


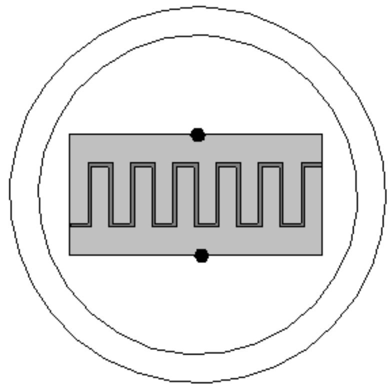
Fairly good linear! It's not a question of "Rocket Science".

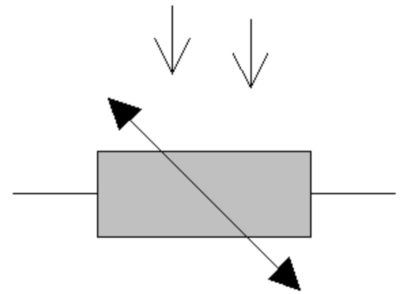
Light depending resistor LDR CDS

- Light depending resistor

LDR photo resistor







Day/Night
street lighting

Flame sensor
for oil burner

LDR photo resistor

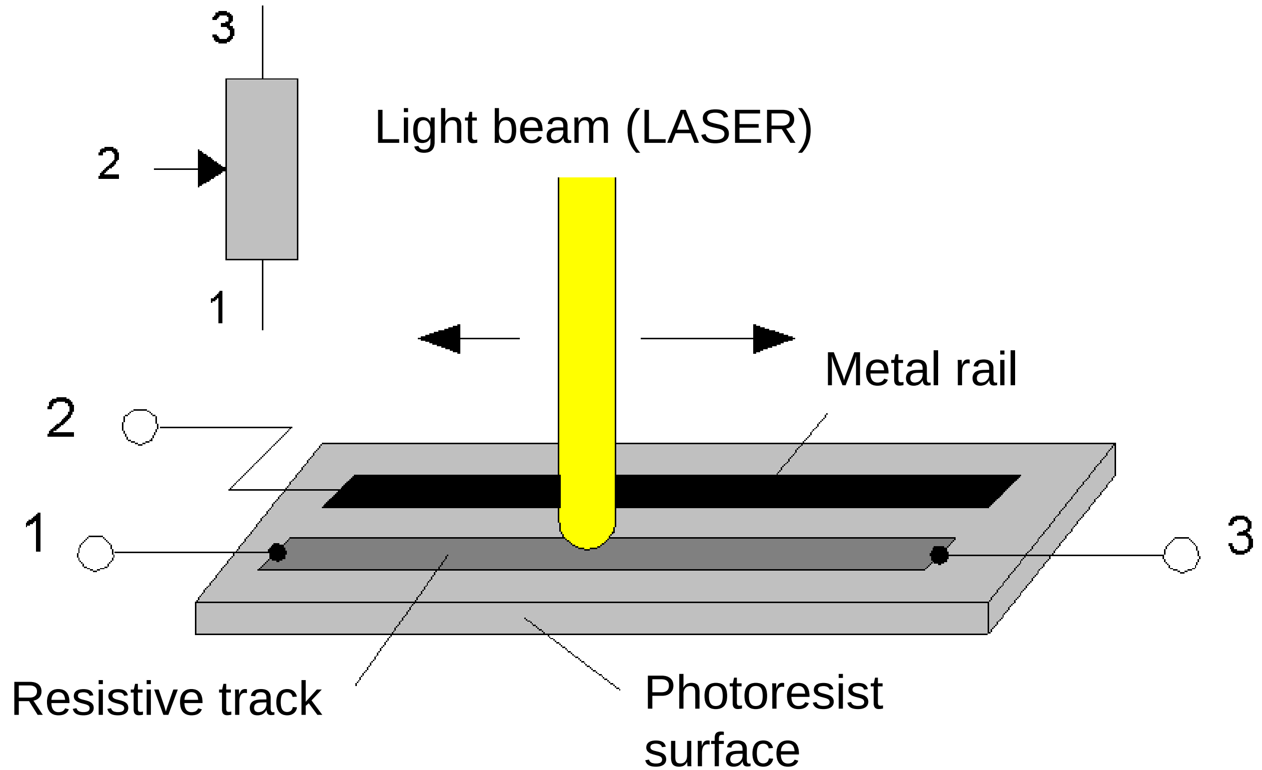
Several drawbacks:

- Hysteresis, different to - from levels – sometimes an advantage (street lighting)
- Long time constant (sec) – gave badly exposed film in cameras …
- Quick aging

CDS contains small amounts of environmental toxin cadmium, but it can probably in the future be replaced with Zn?

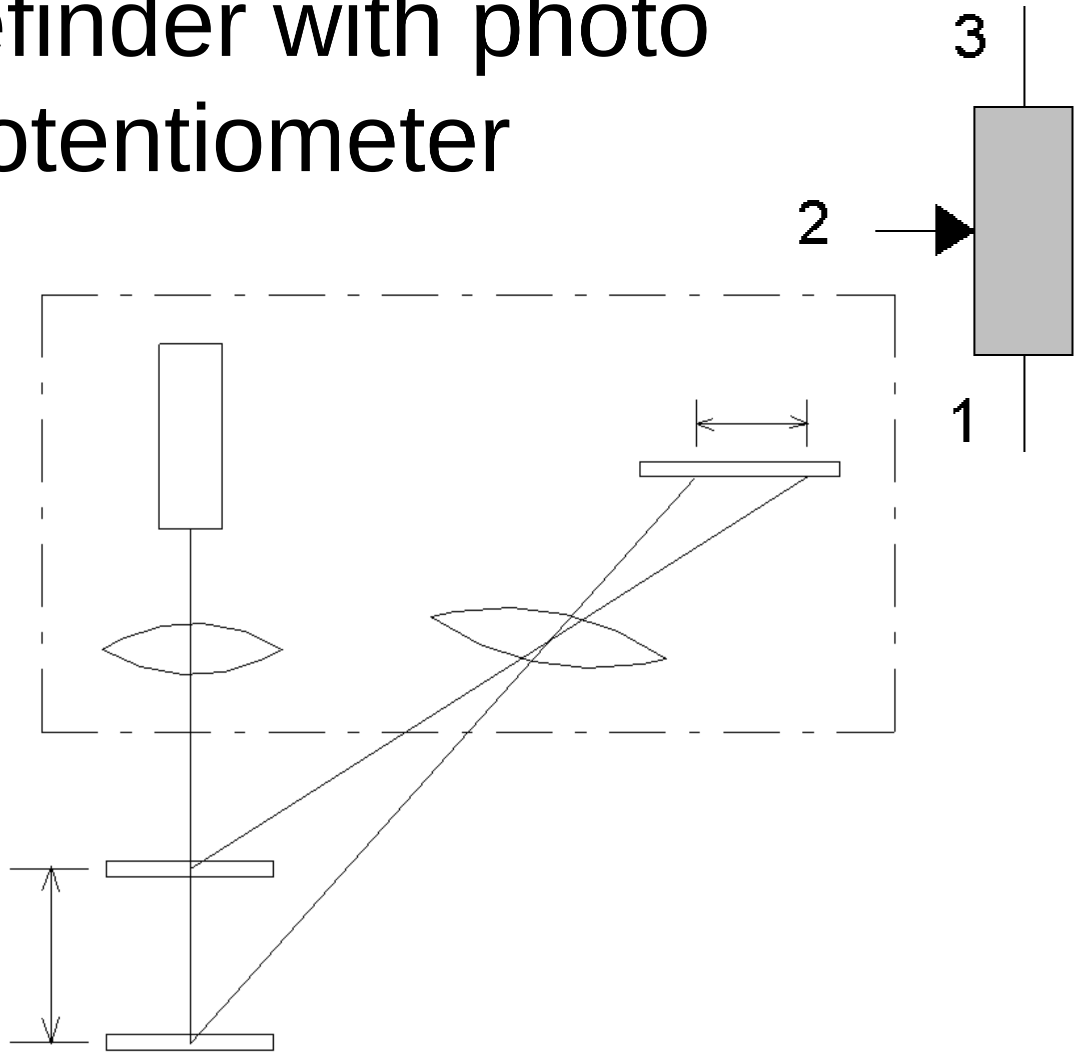
Photo potentiometer

CDS-material can be used in a noncontact potentiometer.



Contactless potentiometer. Where the light beam hits the photoresist surface, the resistance will be small. There is formed a contact point between the resistive track (1) and the metal rail (2).

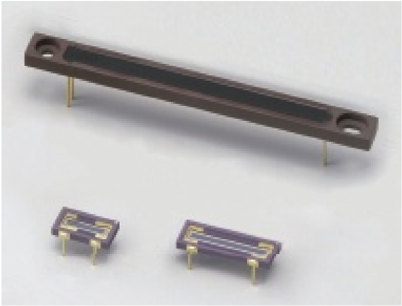
Rangefinder with photo potentiometer



Contactless range finder.

Depending on the distance to the object the light beam is reflected to different points on the photo-potentiometer.

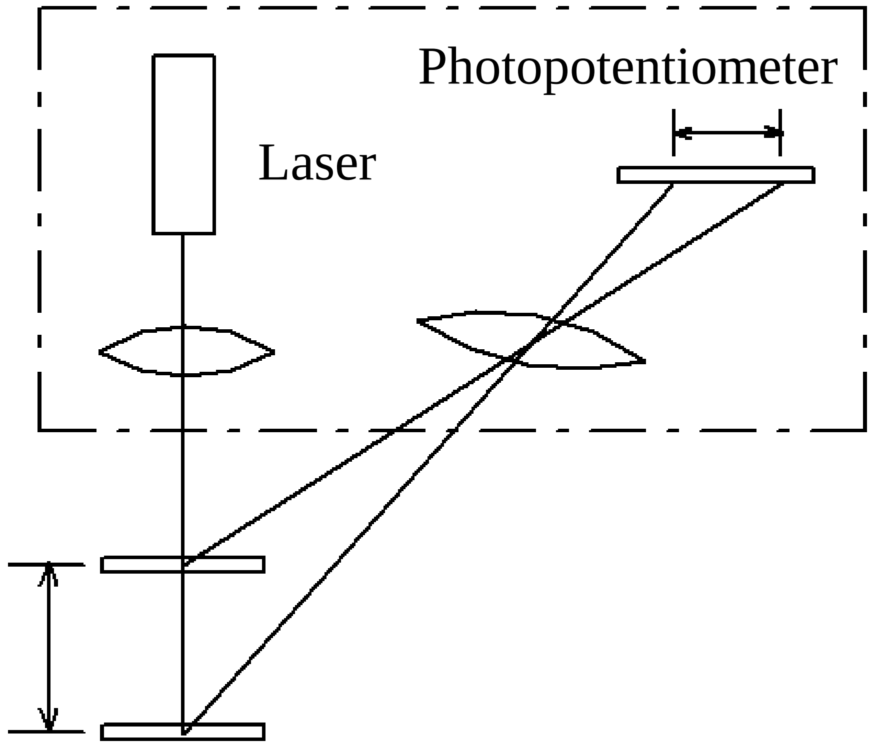
(PSD or CCD instead)

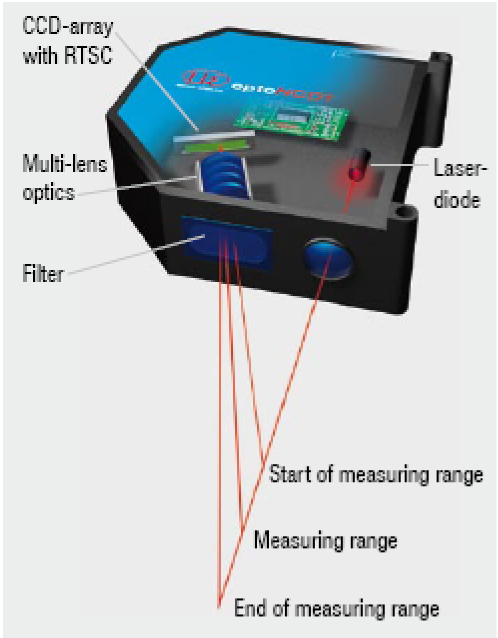


Alternatives to CDS fotopotentiometer are PIN photodiode. (With analog readout)

A common CCD elements from a scanner has 1024 pixels in a row. It is also useful as fotopotentiometer. (With digital readout)

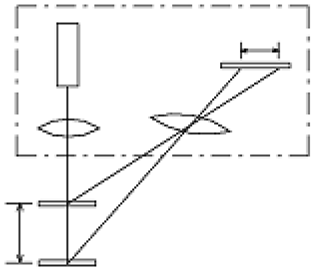
Triangulating

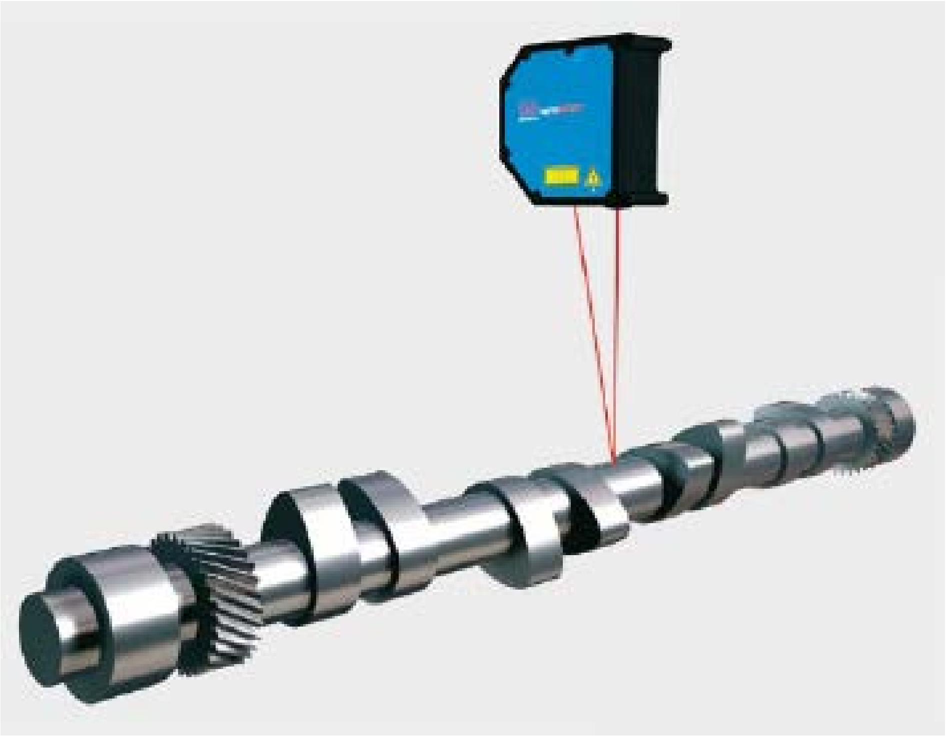




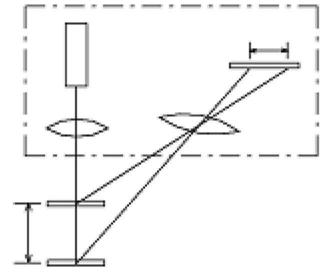
Should not incident angle be equal to the output angle?
– Here it is a question of lasers and diffuse reflection!

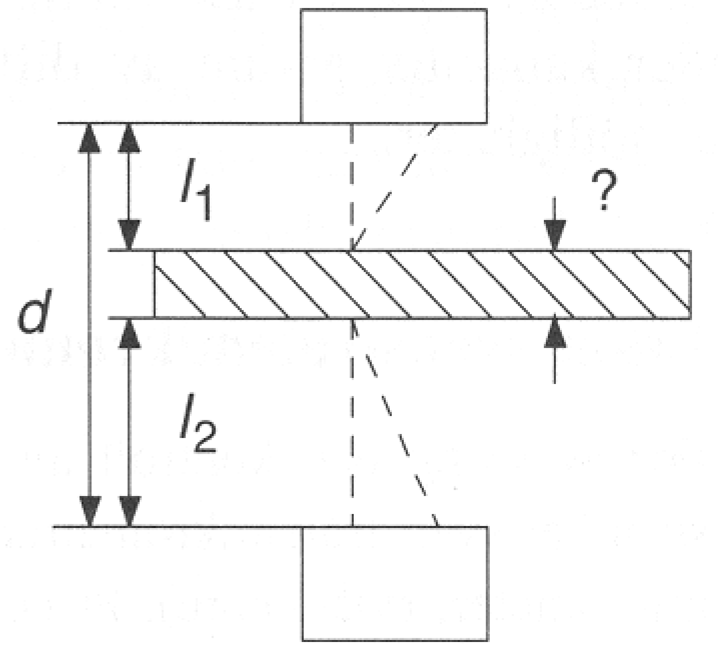
One meter

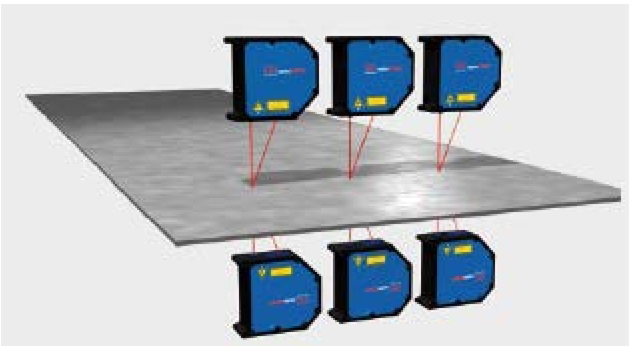




Two meters?







No matter where you place the item between the two gauges, the thickness ”?” can be calculated as d - l_1 - l_2.