Physics Factsheet

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The Negative Temperature Coefficient (NTC) Thermistor and the Light-Dependent Resistor

This Factsheet will explain:
- how the resistance of an NTC Thermistor varies with temperature;
- how the resistance of a Light-Dependent Resistor varies with light level;
- how the effects may be demonstrated experimentally;
- how LDRs or thermistors may be used to vary voltage.

Before studying this Factsheet, you should ensure that you are familiar with:
- the concept and definition of resistance from your GCSE course – that Ohm found the ratio of the P.D. across a component to the current through it to be a constant, which he called "resistance";
- that this simple concept does not hold for all materials or components; that "resistance" is not a universal constant, but is still a useful concept in prescribed circumstances. Hence, a definition of "resistance" as the ratio of V/I in a given set of conditions;
- that in metals resistance increases with temperature.

You may also find it useful to look at Factsheet 7 – Current, voltage and resistance and at Factsheet 28 – Graphs in physics.

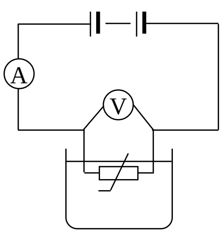
Resistance

> ***Resistance is defined as the ratio of the voltage across a component to the current through it.***

The concept of resistance varying with changing conditions is usually presented in one of two ways:
- either as a graph of resistance against a particular factor such as temperature or light intensity,
- or as current/voltage characteristics. In this case, the resistance is related to the gradient of the graph.
- The graph of the current/voltage relationship is often presented with the other 3 quadrants of the graph shown, not just the usual positive/positive one. This is because for some components there is a difference if the current is reversed.
- The graphs are sometimes presented as voltage/current and sometimes as current/voltage. **Always** look carefully to see which way round the graph is plotted.

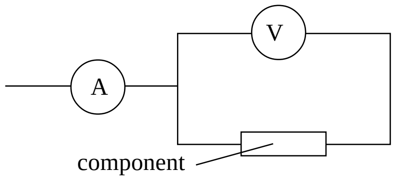
> *Always check to see which way round a graph is plotted. The resistance is the gradient of a voltage/current graph, but the **inverse** gradient of a current/voltage graph.*

Investigating the voltage/current characteristics for a thermistor with changing temperature.

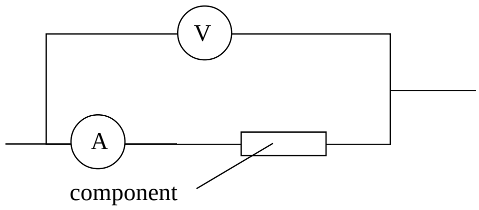


Apply a suitable voltage across a thermistor to give a reasonable reading on the ammeter. Take pairs of values of *V* and *I* for changing temperatures from 0^0C (by immersing in ice) to 100^0C (by heating the water to boiling). Ensure that the temperature is even throughout the water at each reading by stirring. Repeat each reading and average them to increase accuracy. Calculate R for each pair of values and plot *R* against *t*.

This investigation can be done very conveniently using datalogging equipment. Advantages include a large number of values due to the possible frequency of sampling, and automatic graph plotting facilities. An ohmmeter can be used in place of the voltmeter and ammeter. Using an ohmmeter reduces the errors involved in using ammeter/voltmeter. When using the ammeter/voltmeter, either the ammeter measures the current through the voltmeter as well as that through the component:

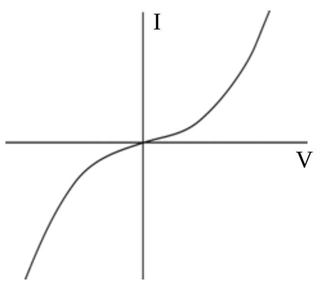


or the voltmeter measures the P.D. across the ammeter as well as that across the component.



Either method introduces an error; though this should be small if the meters are close to being "ideal" i.e. the ammeter has a very small resistance and the voltmeter a very high resistance.

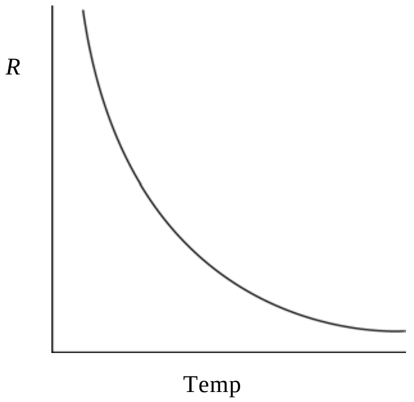
The Current/Voltage characteristic of a NTC Thermistor
The graph obtained is of the form shown below:



On the I/V plot the resistance is the inverse of the gradient, i.e. the resistance is **decreasing**. This is because as V increases, the thermistor gets hotter.

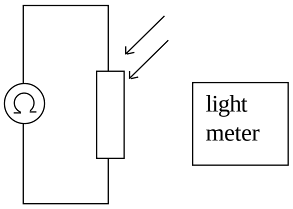
> *For the NTC Thermistor the resistance **decreases** as temperature increases.*

A plot of resistance against temperature would look as below:



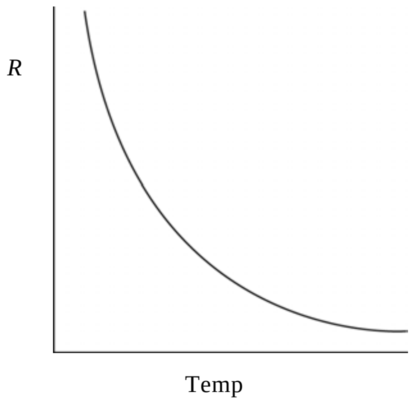
The Light Dependent Resistor

The dependence of the resistance of an LDR on the intensity of light can be investigated using the apparatus shown below:



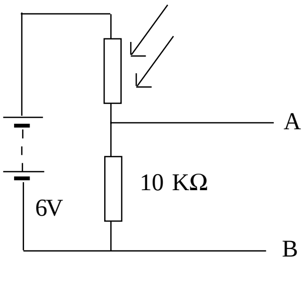
The ambient light level is varied and read by the light meter. For each light level, the resistance of the LDR is measured with a digital ohmmeter. The light level may be varied by altering the source of light, or by having a strong source of light moved further back in stages, or by putting successive sheets of paper over a source. Obviously, it is important that the light meter is reading the light intensity at the position of the LDR, so care must be taken to achieve this.

The graph of the dependence of the resistance on the light intensity is a below:



Using a Thermistor or an LDR to control voltage

A thermistor or an LDR can be used as part of a potential divider to control voltage.



The resistance of the bottom resistor is fixed at, say, 10 kΩ. The LDR in the top part of the potential divider has a resistance that will vary depending on the light intensity. It may be from the order of 1MΩ in low light, to 1kΩ in higher light levels. In strong light, the resistance of the LDR will be about 1kΩ, hence the P.D. between A and B will be about (10k/11k) 6V i.e. not far off 6V.

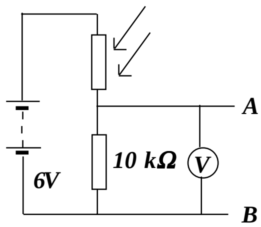
When the LDR is in low light, its resistance will be around 1MΩ, so the P.D. between A and B will be about: $\dfrac{10 \times 10^3}{1001 \times 10^3} \times 6V$ i.e. 0.06V.

Thus the P.D. between A and B will vary from 6V to almost nothing depending on the light level incident on the LDR. This arrangement can be used to trigger a change from on to off in a logic gate, which can turn various devices on or off. This concept is used extensively in automatic electronic control systems, where the system is required to respond to changes in light level. The value of the fixed resistor in the bottom half of the potential divider can be set to determine the precise light level at which the logic gates switch.

An NTC thermistor can be used in exactly the same way to respond to changes in temperature, rather than light intensity. This arrangement is used extensively in devices such as fire alarms and automatic sprinkler systems.

Worked Example

The following circuit can be used as a lightmeter.



(a) The maximum value of the LDR is 900kΩ. What is the reading on the voltmeter for this resistance (assuming that the voltmeter has a very high resistance)? (2)

(b) The minimum value of the LDR is 1kΩ. What is the reading on the voltmeter for this resistance? (2)

(c) Explain how the readings on the voltmeter enable this circuit to be used as a lightmeter. (2)

(d) Explain what difference it would make to the readings if the voltmeter did not have a very high resistance. (2)

Answers

(a) The reading on the voltmeter will be:

$$\frac{10 \times 10^3}{910 \times 10^3} \times 6V = 6.6 \times 10^{-2} V$$

(b) The reading on the voltmeter will be:

$$\frac{10 \times 10^3}{11 \times 10^3} \times 6V = 5.45V$$

(c) The readings on the voltmeter are related to the light intensity and so can be used as a measure of it. Since it is not a linear relationship, a calibration curve would be drawn up to show the light intensity corresponding to each meter reading.

(d) If the voltmeter did not have a very high resistance, it would affect the voltage between A and B, the reading would be:

$$\frac{R_{AB}}{R_t} \times 6V$$

where R_{AB} is the parallel combined resistance of the 10kΩ and the voltage of the voltmeter, i.e.

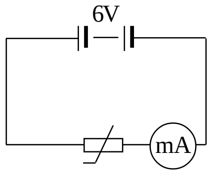
$$\frac{1}{R_{AB}} = \frac{1}{10 \times 10^3} + \frac{1}{R_{voltmeter}}$$

and R_t is the series combined resistance of R_{AB} and the resistance of the LDR.

Exam Workshop

This is a typical poor student's answer to an exam question. The comments explain what is wrong with the answers and how they can be improved. The examiner's mark scheme is given below.

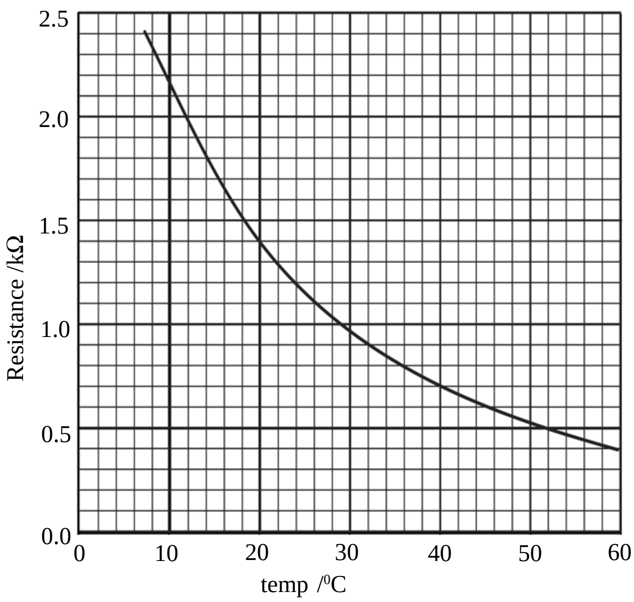
An NTC thermistor is used in the following circuit to make a temperature sensor.



(a) Explain how the circuit works. (3)
The reading on the mA is related to the temperature. *1/3*

> The candidate has scored a mark for knowing how the reading is achieved, but shows no understanding of the principles behind the device.

(b) The graph shows dependence of the resistance on temperature.



What will be the reading on the milliameter when the thermistor is at a temperature of 20^0C? **(3)**
1.4kΩ *0/3*

> The pupil has merely read the value of resistance from the axis, and not used V = IR to calculate the current.

Examiner's Answers

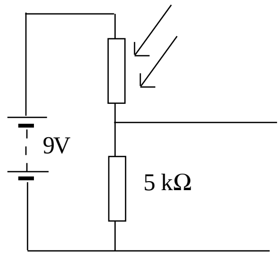
(a) *The resistance of the NTC thermistor decreases with temperature, so the current increases with temperature. A calibration curve can be drawn up, which shows the corresponding temperature for each current value.*

(b) *From the graph, the resistance of the thermistor at 20^0C will be 1.4kΩ, so*

$$I = \frac{V}{R} = \frac{6}{1.4 \times 10^3}$$

Questions

1. Define "resistance" for a circuit component.
2. What is meant by
   (a) An NTC thermistor
   (b) An LDR?
3. Describe how you would obtain results to plot a graph to show the temperature dependence of an NTC thermistor.
4.



In the arrangement shown in the diagram, what is the potential difference across the 5kΩ resistor when the resistor of the LDR is
(a) 1kΩ
(b) 100kΩ?

5. Describe how an NTC thermistor could be used in a potential divider arrangement for use in a fire alarm.

Answers

1. The resistance of a component is the ratio of the potential difference across it to the current through it.
2. (a) An NTC thermistor is a resistor whose resistance decreases as temperature increases.
   (b) An LDR is a resistor whose resistance varies with the light intensity incident on it. The resistance is lower for greater intensity.
3. See text
4. (a) The P.D across the 5kΩ is
   $\frac{5}{6} \times 9V = 7.5V$
   (b) The P.D across the 5kΩ in this case is
   $\frac{5}{100} \times 9V = 0.45V$
5. An NTC Thermistor could be used in an arrangement like that in question 4, with the thermistor in place of the LDR. When the temperature rises, the resistance of the thermistor will go down, so the P.D. across the 5kΩ resistor will rise. This could trigger a logic gate at a set value, switching on an alarm or an automatic sprinkler. The value of the fixed resistor should be chosen to determine the temperature at which the gate switches on.

Acknowledgements:
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