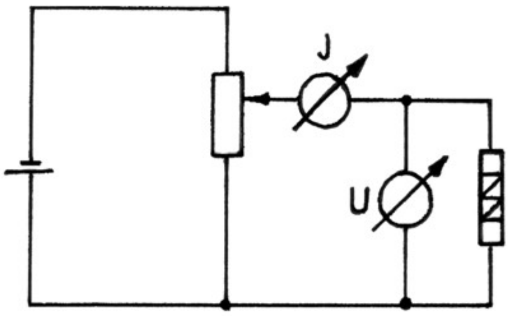
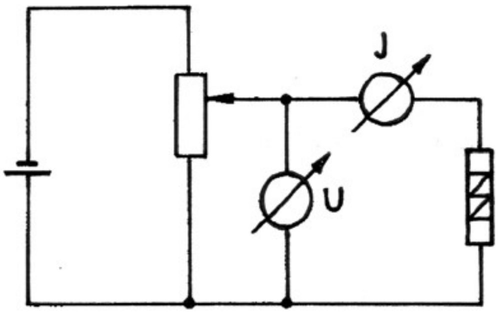
Solution of the experimental problem:

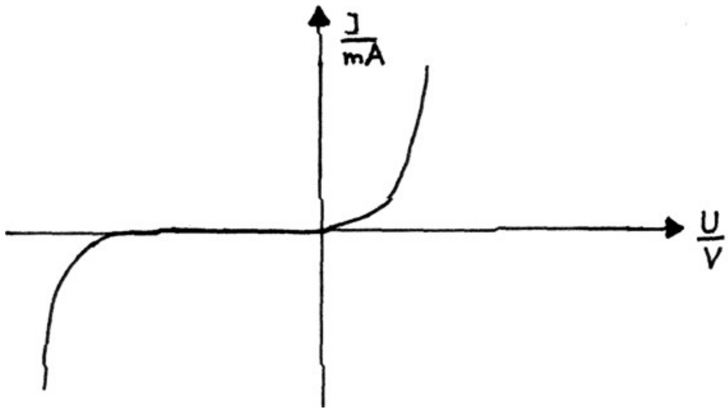
a) Some considerations: the product of the voltage across the semiconductor element U and current I through this element is not allowed to be larger than the maximum permitted load of 250 mW. Therefore the measurements have to be processed in a way, that the product $U \cdot I$ is always smaller than 250 mW.

The figure shows two different circuit diagram that can be used in this experiment:





The complete current-voltage-characteristics look like this:



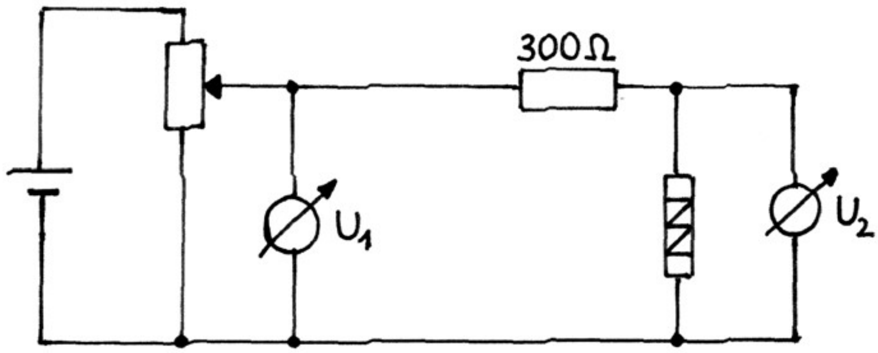
The systematic error is produced by the measuring instruments. Concerning the circuit diagram on the left ("Stromfehlerschaltung"), the ammeter also measures the current running through the voltmeter. The current must therefore be corrected. Concerning the circuit diagram on the right ("Spannungsfehlerschaltung") the voltmeter also measures the voltage across the ammeter. This error must also be corrected. To this end, the given internal resistances of the measuring instruments can be used. Another systematic error is produced by the uncontrolled temperature increase of the semiconductor element, whereby the electric conductivity rises.

b) The dynamic resistance is obtained as ratio of small differences by

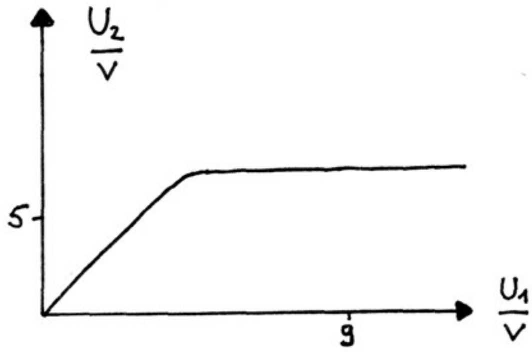
$$R_i = \frac{\Delta U}{\Delta I} \qquad (1).$$

The dynamic resistance is different for the two directions of the current. The order of magnitude in one direction (backward direction) is 10 Ω ± 50% and the order of magnitude in the other direction (flux direction) is 1 Ω ± 50%.

c) The complete circuit diagram contains a potentiometer and two voltmeters.



The graph of the function $U_2 = f(U_1)$ has generally the same form for both directions of the current, but the absolute values are different. By requesting that the semiconductor element has to be placed in such a way, that the output voltage U_2 is as high as possible, a backward direction should be used.



Comment: After exceeding a specific input voltage U_1 the output voltage increases only a little, because with the alteration of U_1 the current I increases (breakdown of the diode) and therefore also the voltage drop at the resistance.

d) The output voltages belonging to U_1 = 7 V and U_1 = 9 V are measured and their difference ΔU_2 is calculated:

$\Delta U_2 = 0.1$ V ± 50% (2).

Comment: The circuit is a voltage divider circuit. Its special behaviour results from the different resistances. The resistance of the semiconductor element is much smaller than the resistance. It changes nonlinear with the voltage across the element. From $R_i << R_V$ follows $\Delta U_2 < \Delta U_1$ in the case of $U_1 > U_2$.

e) The semiconductor element is a Z-diode (Zener diode); also correct: diode and rectifier. The circuit diagram can be used for stabilisation of voltages.

Marking scheme

Problem 1: "Rotating rod" (10 points)

Part a	1 point
Part b – cases 1. and 2.	1 point
– forces and condition of equilibrium	1 point
– case Z downwards	2 points
– case Z upwards	2 points
– calculation of $r_{1,2}$	1 point
– case $\alpha > \beta$	1 point
– case $\alpha \le \beta$	1 point

Problem 2: "Thick lens" (10 points)

Part a	1 point
Part b – equation (1), equation (2)	2 points
– physical restrictions, equation (3)	1 point
– discussion of different cases	2 points
– shapes of lenses	1 point
Part c – discussion and equation (4)	1 point
Part d	2 point

Problem 3: "Ions in a magnetic field" (10 points)

Part a – derivation of equations (1) and (2)	1 point
– derivation of equation (4)	1 point
Part b – characteristics properties of the particle paths	3 points
Part c – boundaries of the magnetic field for the three cases	3 points
Part d	2 points

Experimental problem: "Semiconductor element" (20 points)

Part a – considerations concerning overload, circuit diagram, experiment and measurements, complete current-voltage- -characteristics discussion of the systematic errors	6 points
Part b – equation (1) dynamic resistance for both directions correct results within ±50%	3 points
Part c – complete circuit diagram, measurements, graph of the function $U_2 = f(U_1)$, correct comment	5 points
Part d – correct ΔU_2 within ±50%, correct comment	3 points
Part e – Zener-diode (diode, rectifier) and stabilisation of voltages	3 points

Remarks: If the diode is destroyed two points are deducted.

If a multimeter is destroyed five points are deducted.