

Test about Voltage - A Basic Term in Electricity Results

from students and teachers in
Kiel (Germany)
Kosice (Slovakia),
Murcia, Santander (Spain),
North Carolina State University (US)

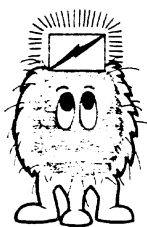
The following test has been administered

		Group #
with 1st.year Biology students,	N = 53	1
with physics teachers ,	N = 44	2
with 1st.year physics students	N = 15	3
with 3rd.year physics students,	N = 6	4
with students on engineering	N = 15	5
at the North-Carolina-State University with 1st.-year students.	N = 115	6

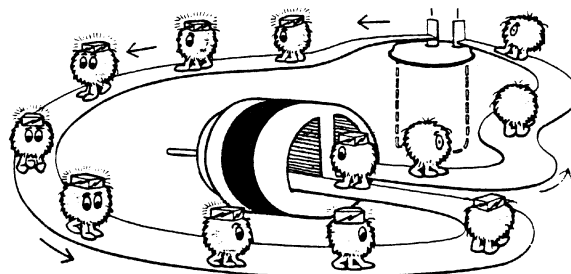
The US-students had finished an electricity course, where surface charges have explicitly been taught by Bruce Sherwood. Their results could serve as some kind of benchmark.

Assignment 1.

In some books a causal model for an electric circuit is presented as shown in the following picture.



Electron with and without energy



Electrons carrying energy from the battery to the motor to the motor

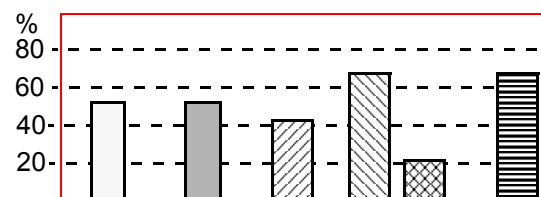
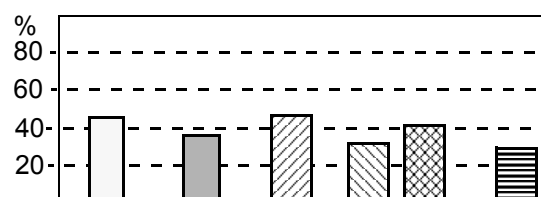
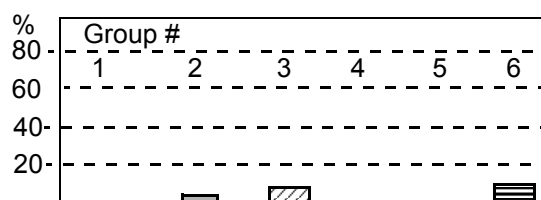
On the line from the battery to the motor the electrons carry the energy to drive the motor and on the line back to the battery, the electrons are without energy and need to be reloaded.

Which of the following statements is correct?

1) This model for the electric current is acceptable.

2) The model is only partly acceptable because the electrons on their way back to the battery are not completely without energy as shown in the figure but rather they have some energy. However, they have less energy than on their way to the motor.

3) The model is not acceptable because in a good model the electrons in both lines should play equally important roles in respect to energy and to drive the motor.



Comment:

This item is neither related to surface charges nor to transition processes.

Students, who accept this model could be tempted to do so because having learned:

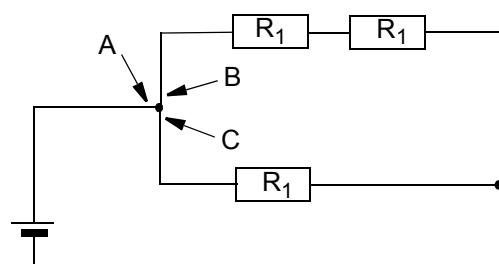
Potential difference or voltage = Energy per charge.

At least they seem to have internalised a rather problematic model for the electric circuit.

This hypothesis would have to be grounded on interviews with those students who have accepted this model.

Assignment 2.

In an electric circuit with a branching point, the current is split up at the branching point according to the resistors within the different parallel branches.



The larger the resistor in such a branch, the smaller the current through this branch.

Is there any difference in the physical state of the wires at A, B and C, adjoining the branching point from different sides, which can explain the correct splitting of the stream of electrons?

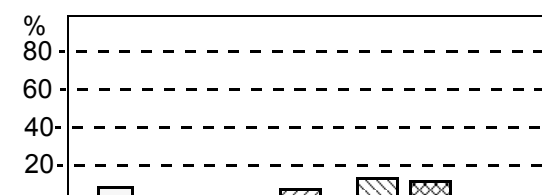
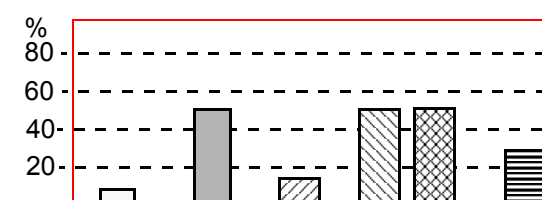
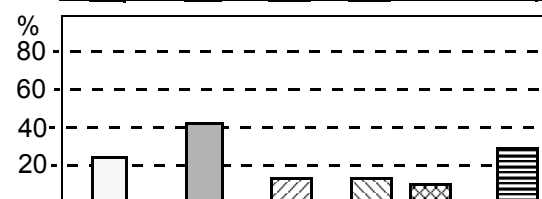
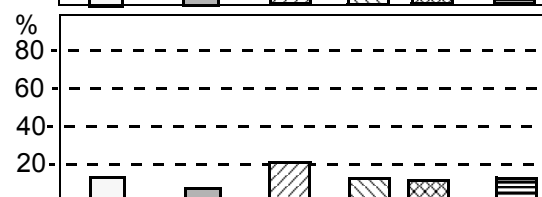
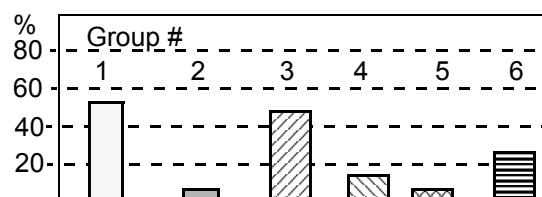
1) No, there is no difference in the physical state of the three wires near the point of branching.

2) There must be a difference but I cannot say which one.

3) The density of electrons throughout the three cross sections is different.

4) The density of electrons at the surface of the three cross sections is different.

5) The electrons at the three cross-sections have different energy.



Comment:

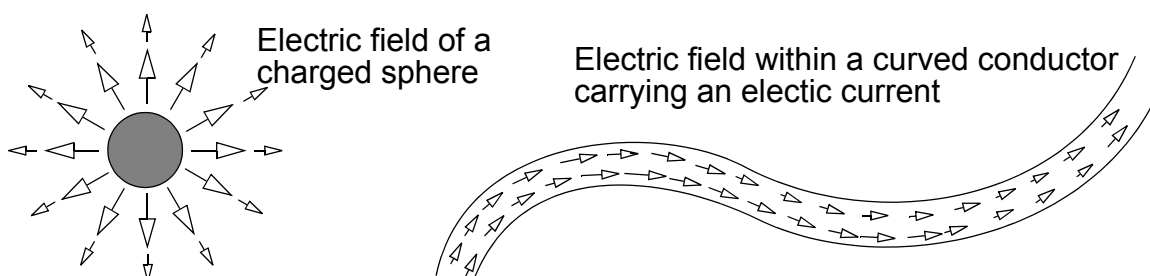
Astonishing that only about 30% of US-students master this item. From Bruce I learned that there may be some difficulty due to wording. What is meant by „physical state“?

50% of the Slovakian teachers and 3rd year Spanish students are doing fine. The question is, if not 100% of physics teachers should know the answer.

Assignment 3.

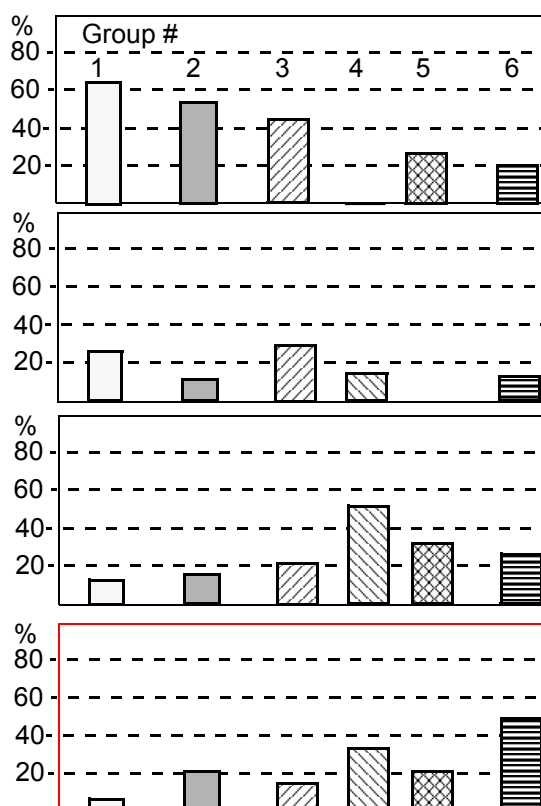
Coulomb's law states that the electric field of a point charge is depending on distance according to $1/r^2$. Based on this law the field of charged objects can be calculated and it follows that in practically all cases the static electric field around such objects is also depending on distance.

In a uniform curvilinear resistive wire of constant diameter, which carries an electric current, the electric field within the wire, which is driving the current, is NOT depending on distance. It is constant and always directed parallel to the axis of the wire, whatever be the curvature of its bending. This seems to be in contradiction with the fact, stated above, that the electric field around a charged object is depending on distance.



Which of the following answers makes sense to you?

- 1) I do not see a contradiction between these two cases. One case is static, the other is dynamic and both cases cannot be compared.
- 2) There must be something along the wire which causes the field to be constant and parallel to the axis of the wire, but I do not know what it is.
- 3) Along the wire the density of the drifting electrons varies and causes the electric field to be constant and parallel to the axis of the wire.
- 4) **The surface of the wire is charged differently.**

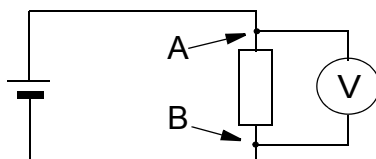


Comment:

This result fits perfectly to my expectation. The US-students are ahead and only 20% of the teachers know the answer.

I wonder why the first item is so popular. If possible we should ask some of those teachers to learn about their thoughts.

Assignment 4.



As shown in the circuit, there is a potential difference across a resistor, if it is connected to a battery and a current is flowing.

The question is: Is there any difference in the physical state between the contact points A and B on the opposite sides of the resistor?

Which of the following answers do you think is correct or makes sense to you?

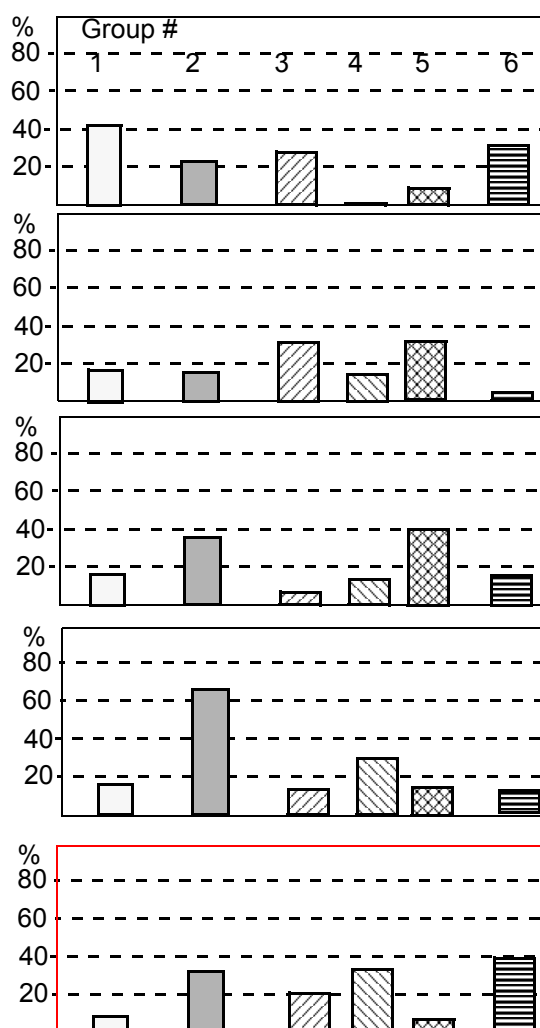
1) There is no difference in the physical state between the contact points A and B.

2) There must be a difference but I can't say anything about it.

3) Throughout the cross-section of the wires at A and B the density of the free electrons is different.

4) The drifting electrons at A and B have different energy.

5) The surface of the wire at A and B is charged differently.



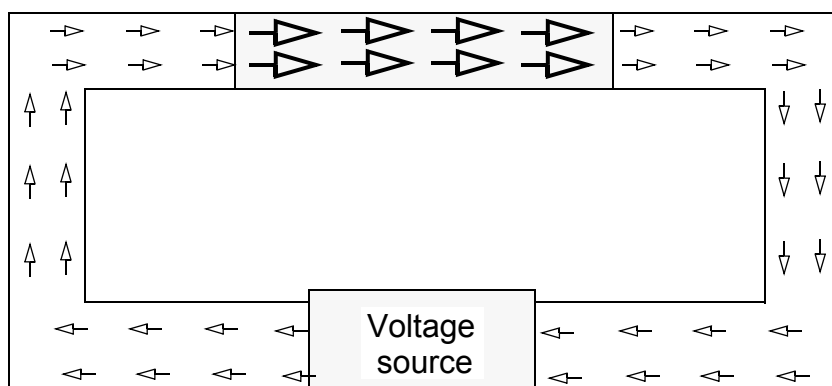
Comment:

This result also fits to my expectation.

The high score of the Slovakian teachers for item 4 is kind of astonishing. May be they thought of potential difference and therefore different energy for the two lines. This comes close to the model of assignment 1.

Assignment 5.

Within a simple electric circuit a constant current is flowing through a resistor. For reasons of simplicity the diameters of the conductors and the resistor are given to be the same..

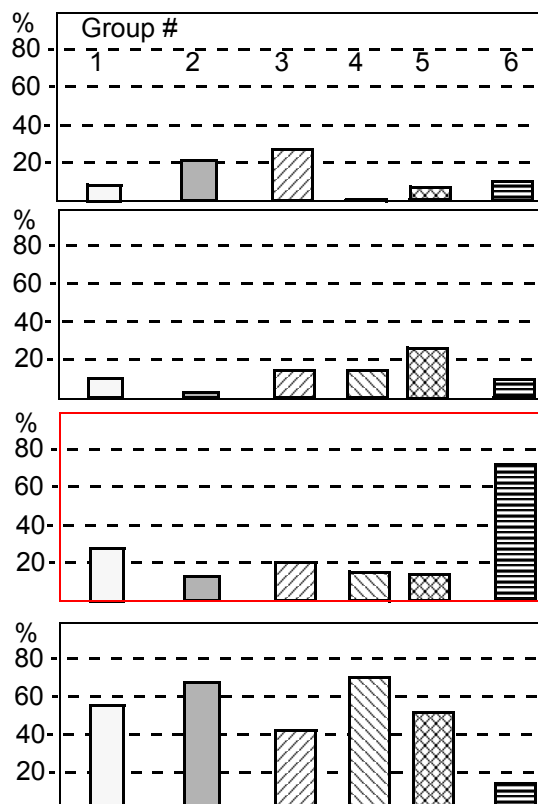


Since there is practically no potential difference along the conductors but mainly across the resistors, it can be concluded that the electric field within the resistor will be much larger than within the conductors.

Where does this extra field within the resistors come from?

Which of the following answers do you think is correct or makes sense to you?

- 1) The extra field is produced by the battery which drives the current.
- 2) There should be extra electrons at one side and positive charges at the other side of the resistor, but I am not sure.
- 3) **There are extra electrons at one side and positive charges at the other side of the resistor.**
- 4) The energy of the drifting electrons, forming the electric current, is different at both sides of the resistor.



Comment:

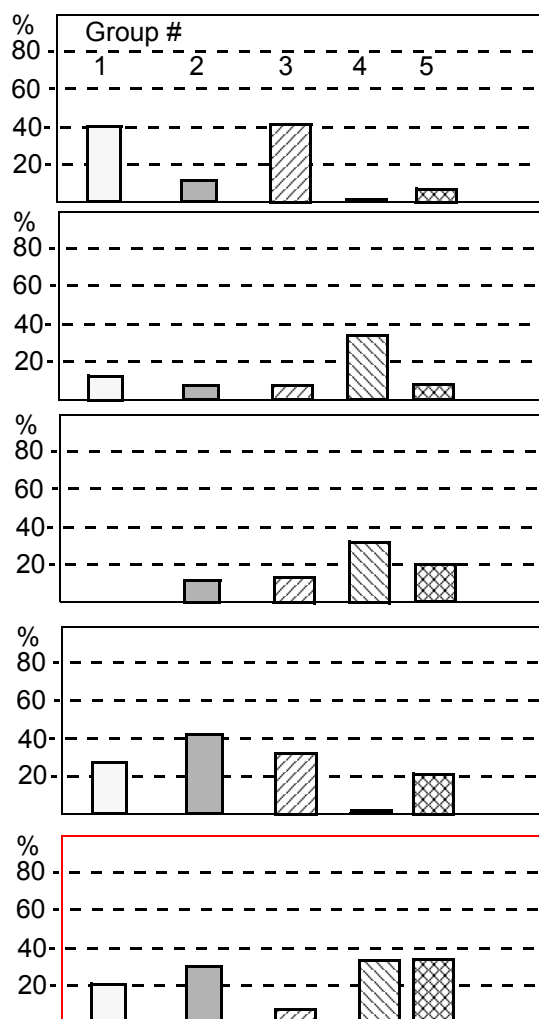
Again a clear fit with my expectation. In the course of Bruce Sherwood this situation is treated explicitly and the positive result is obvious, while only about 20% of the other groups come up with correct results.

Assignment 6.

Within an electric circuit, consisting of a battery and a single resistor, a constant current is flowing according to Ohm's law. If the resistivity of the resistor is increased, the current is decreased to a new steady state.

Which of the following statements about the underlying mechanism of transition is correct or makes sense to you (more than one may be correct)?

- 1) I have never heard about transitions between steady states of currents in electric circuits.
- 2) There must be some kind of mechanism, but I do not know what it is.
- 3) The mechanism is in principle the same as if a capacitor is charged.
- 4) A change in density of the drifting electrons, forming the current, is travelling as a wave front along the wire to establish a new steady state.
- 5) A change in density of the surface charges is travelling like a wave front along the wire to establish a new steady state.



Comment:

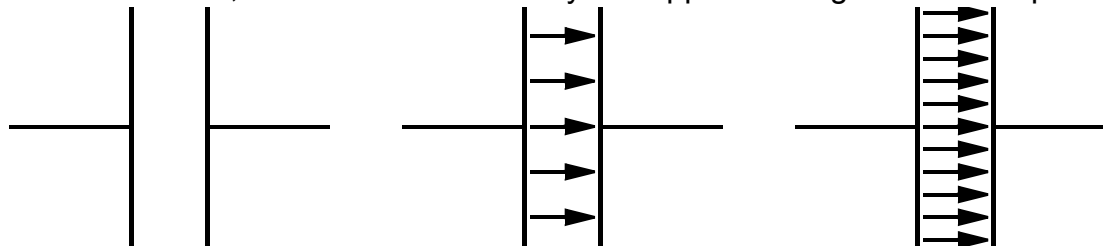
While assignments 1 to 5 deal explicitly with surface charges, the following items 6 to 10 focus more on transition processes where of course also surface charges are involved.

Bruce Sherwood decided for this round not to take this part of the test. We will have to work on better wording and images.

The rather low result of 20 to 30% of the two strong groups - teachers and 3rd year students - indicate, how badly transition processes are treated when the so-called simple electric circuit is discussed.

Assignment 7.

When a capacitor is being charged, the electric field inside is increasing from zero to its maximal value, which is determined by the applied voltage and the capacitance C .



Increasing field strength within a capacitor when being charged

On one side of the capacitor, electrons flow through the connecting wire to the inner surface and on the other side electrons flow from the surface to the connecting wire - leaving positive ions on the surface behind.

The following statements relate to the process of change of the electric field inside of the capacitor.

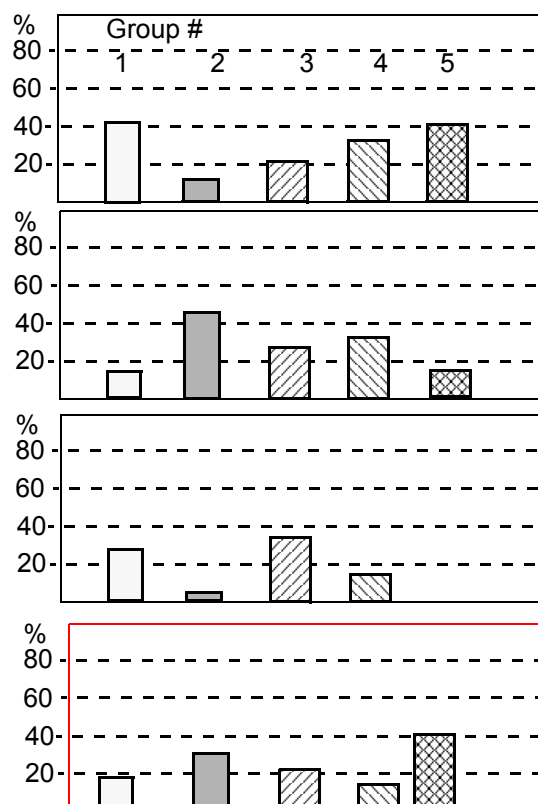
Please indicate which statement does correspond with what you know (or do not know) about this process.

1) The electric field inside the capacitor is formed starting from the appearing negative electrons at one side and ending on the appearing positive ions at the other side.

2) The electric field inside the capacitor is formed starting from the appearing positive ions at one side and ending on the electrons at the other side.

3) The electric field inside the capacitor is formed starting symmetrically from both appearing charge carriers to the middle.

4) The electric field is formed due to charges on the surface of the connecting wires.

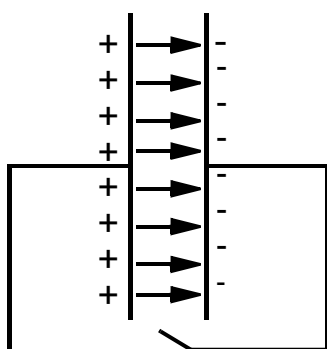


Comment:

This result supports the hypothesis, that transition processes are badly treated in our actual curriculum.

Keep in mind that item 1 to 3 can be excluded by basic principles based on Maxwells equation . $\text{Div } E = -\rho$. Field lines always end on charge carriers.

Assignment 8.



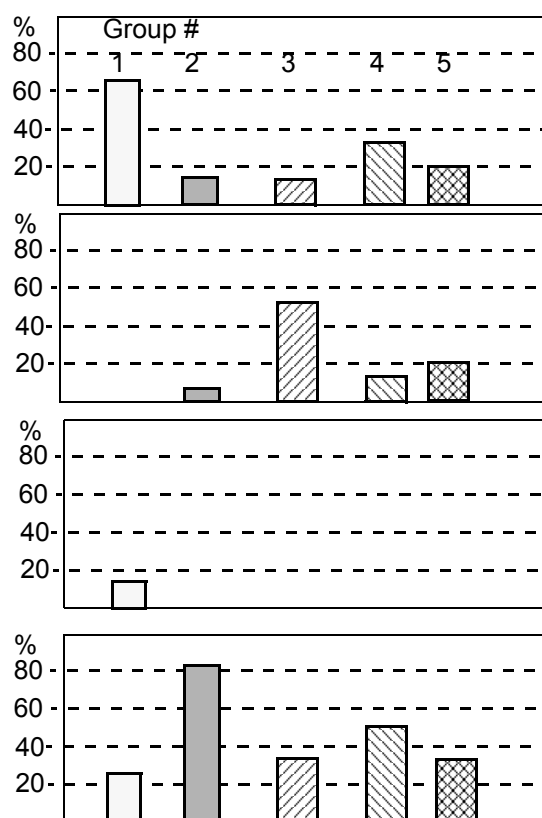
A capacitor consists basically of two large metallic surfaces with a separating isolating and rather thin medium. The density of oppositely charged charge carriers on both opposite surfaces can be very large, because of their mutual interaction. Oppositely charged charge carriers attract each other..

Question:

If these charge carriers attract each other, why will a charged capacitor discharge, if it is shorted by some external wires?

Please chose one or more of the following statements which correspond with what you know (or do not know) about this process.

- 1) The attracting Coulomb forces are overcome by internal atomic forces, based on quantum physics.
- 2) The discharge of the capacitor is due to the fringing fields around the border of the opposite plates.
- 2 a) The discharge of the capacitor is due to a transverse compression of the field lines within the capacitor.
- 3) The discharge of the capacitor is due to surface charges on the external wires.



Comment:

There is a problem with this assignment. In the process of development the 2nd. choice for an answer should have been replaced by the choice 2a. This did not happen and so we have an assignment with 2 correct answers. This is a problem because we now have too many correct answers.

For the time being I propose to take this assignment out, but use it for the future with choice nr. 2a. A third wrong answer would be nice to have. Any ideas?

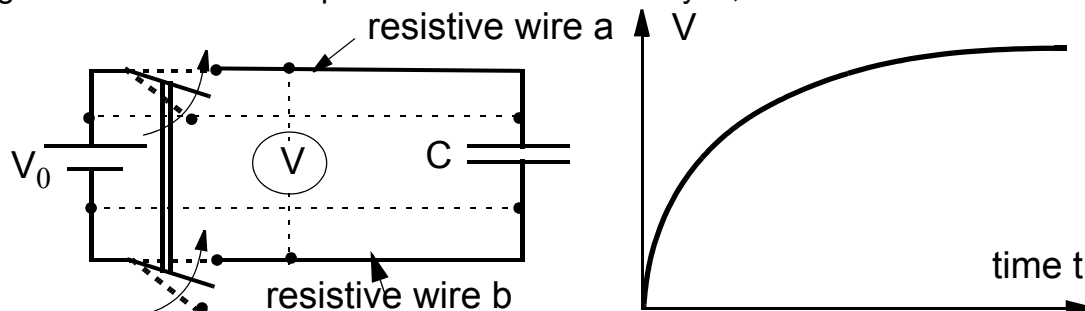
Nevertheless it is remarkable that most of the teachers choose answer 3 and not 2.

Possibly they see the setup as an electrostatic case and have realised that the external wires are charged before the switch is closed.

Assignment 9.

A capacitor is connected to a voltage source by resistive wires (resistance R).

For this circuit the voltage across the capacitor is starting from zero and is then increasing in time. This time dependence is influenced by R , C .



Question:

Where can this time-dependent voltage be measured?

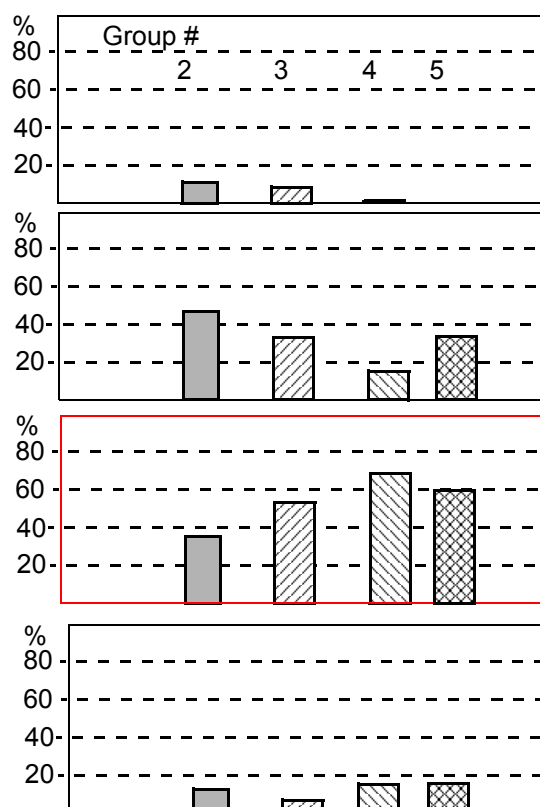
Please choose one or more of the following statements which correspond with what you know (or do not know) about this process

1) The time dependence of V , influenced by R and C , can only be measured inside of the capacitor.

2) The time dependence of V , influenced by R and C , can only be measured just outside of the capacitor.

3) The time dependence of V , measured across any two points of the connecting wires a and b is influenced by R and C .

4) The time dependence of V , measured across any two points of the connecting wires a and b is only influenced by the voltage source. and not by R and C .



Comment:

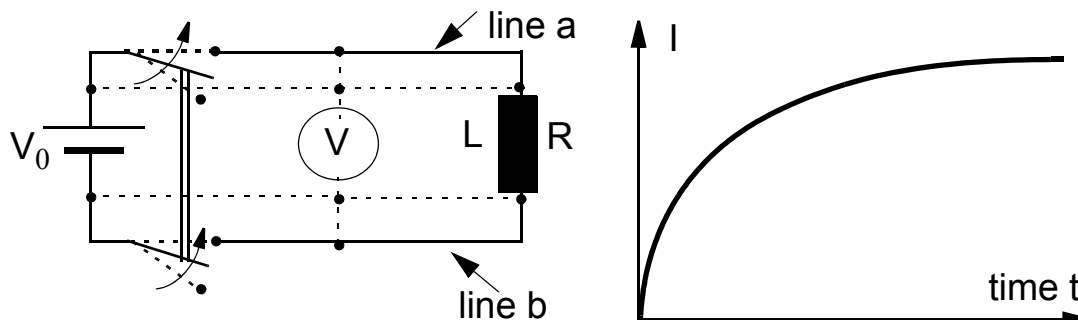
This and the following item was not included in the test at Kiel. The offered time to administer the test was rather limited and the students had not heard anything about inductivity.

I am not very happy with this item because of the wording. What do students understand by „is influenced by“?

And why have so many teachers selected item 2?

Assignment 10.

When a coil (an inductance) with an internal resistance R and an inductivity L is connected to a voltage source, a voltage V_L , due to self-inductance, is induced. The voltage U_L is oriented opposite to the applied voltage V_0 and is proportional to the rate of change of the current I . Its time dependence is influenced by R and L .



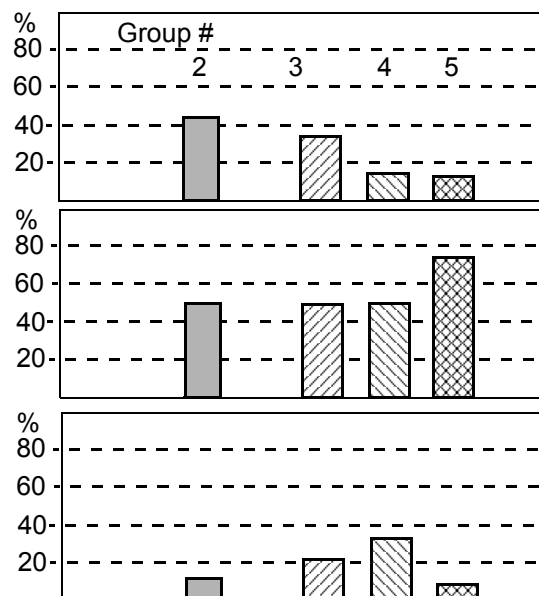
The voltage across the coil, which should be a combination of the applied voltage V_0 and the induced voltage V_L , will also change in time.

Question:

Where can this time depending voltage V be measured?

Please chose one or more of the following statements which correspond with what you know (or do not know) about this process.

- 1) The time dependence of V , influenced by R and L , can only be measured just across the coil.
- 2) The time dependence of V , measured across any two points of the connecting wires a and b is influenced by R and L .
- 3) The time dependence of V , measured across any two points of the connecting wires a and b is only influenced by V_0 and not by R and L .



Comment:

Same comments as for assignment 9. For the next round a better wording and possible better „wrong“ answers would be nice to have.

Questionnaire related to Test about Voltage - A Basic Term in Electricity

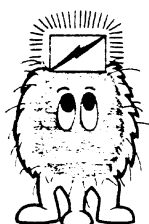
In the following you have the opportunity to judge the assignments, posed in the test about voltage regarding the question:

Are these problems or questions of importance for physics students?

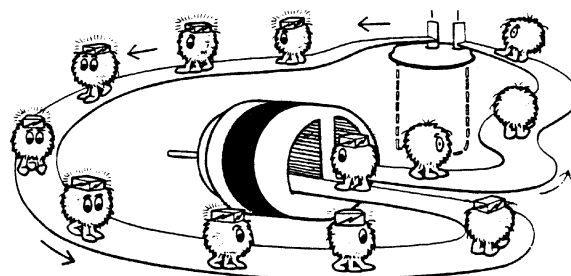
Should physics students, after having finished an electricity course, be able to know the correct answers? Or are these problems rather specific ones and not so important so that physics students do not really have to know the answers?

Please mark for each item separately one of the proposed statements according to your opinion.

To Assignment 1.



Electron with and without energy



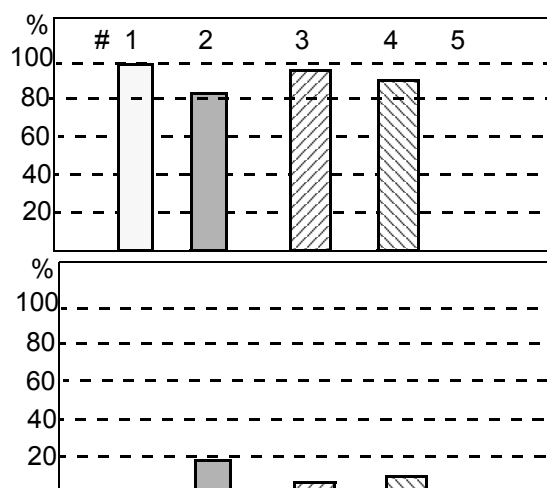
Electrons carrying energy from the battery to the motor

Question: Is this an acceptable model for the electric current?

Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



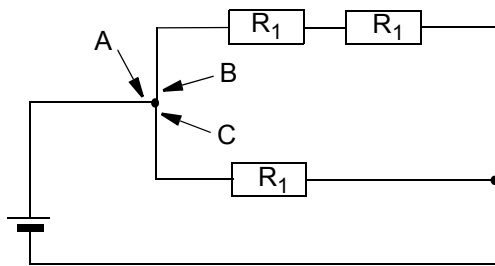
Comment:

With the exception of the group of teachers (see the following assignments) the results are the same for all following assignments. Between 80 to 100% choose item 1.

For me this is an important fact and gives us a good argument, why the curriculum about voltage should include explicitly surface charges and transition processes.

Nevertheless it would be interesting to know, why about half of the teachers as professionals regard these problems as not so important.

To Assignment 2.



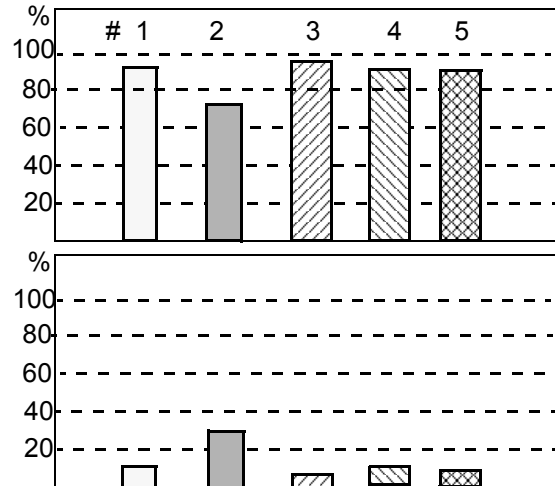
Question:

Is there any difference in the physical state of the wires at A, B and C, adjoining the branching point from different sides?

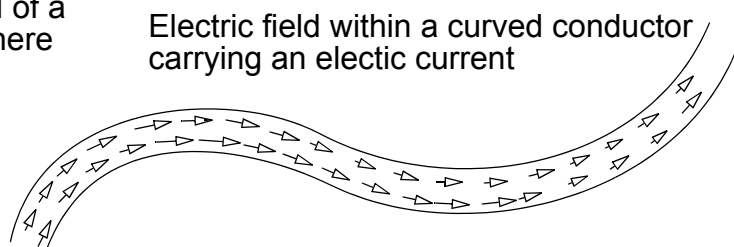
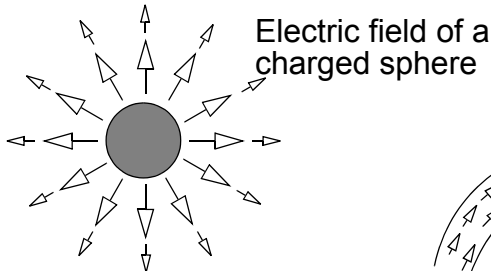
Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 3.

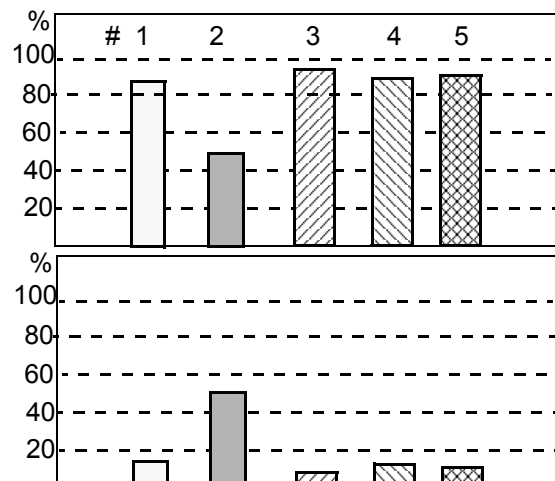


Question: Why is the electric field within the wire constant in magnitude and always oriented parallel to the axis of the wire?

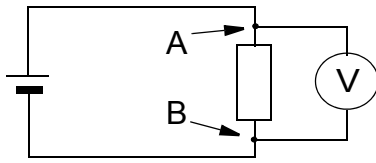
Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



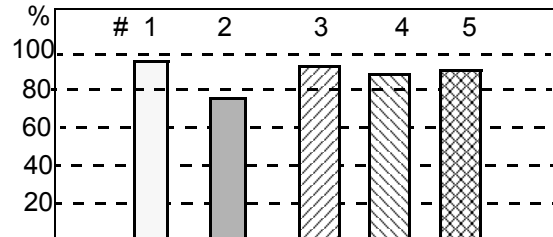
To Assignment 4.



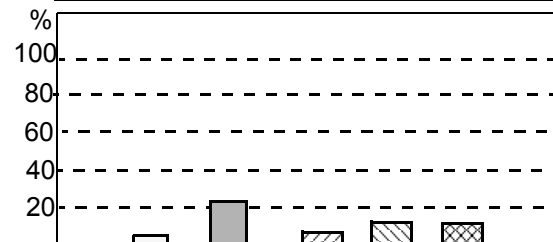
Question: Is there any difference in the physical state between the contact points A and B on the opposite sides of the resistor?

Which of the following statements corresponds with your opinion?

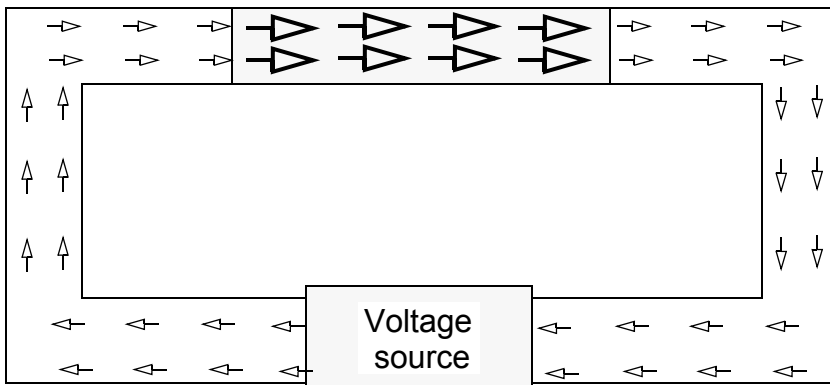
1) The problem is an important one and physics students should know the answer after having finished an electricity course.



2) The problem is a rather specific one and physics students do not really have to know the correct answer.



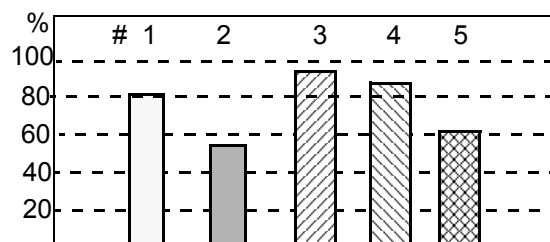
To Assignment 5.



Question: Where does the strong field within the resistors come from?

Which of the following statements corresponds with your opinion?

11) The problem is an important one and physics students should know the answer after having finished an electricity course.



2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 6.

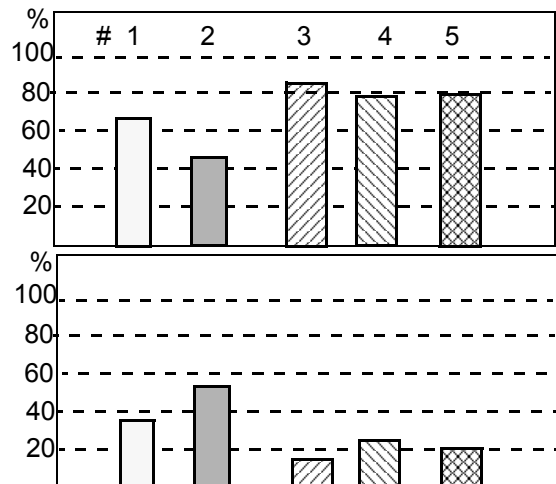
For an electric circuit the focus is set on the transition process between stationary states.

Question: What kind of mechanism drives the transition between stationary states, where Ohm's law is valid?

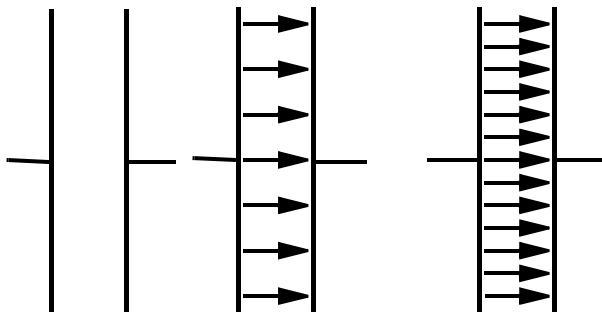
Which of the following statements corresponds with your opinion.

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 7.



Increasing field strength within a capacitor when being charged

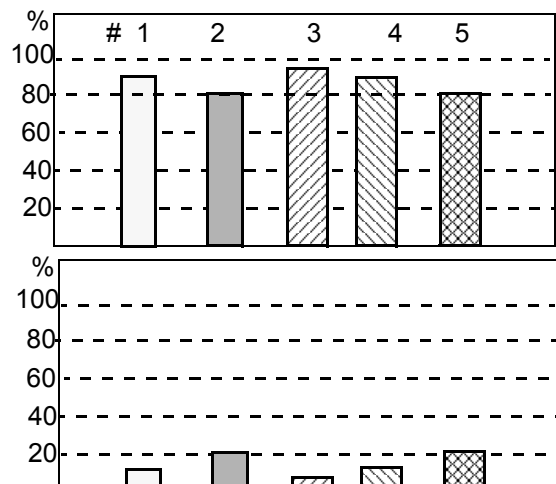
Question:

How is the electrical field formed within a capacitor during the loading procedure?

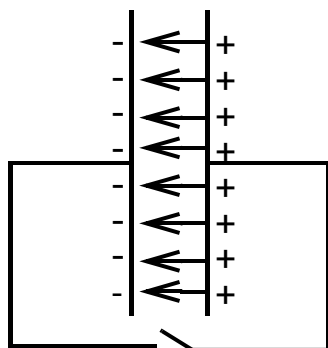
Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 8.



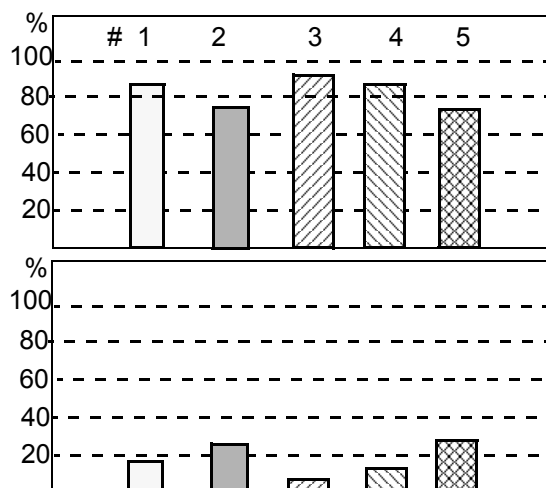
.Question:

If the charge carriers in a charged capacitor attract each other, why will the capacitor discharge, if it is shorted by some external wires?

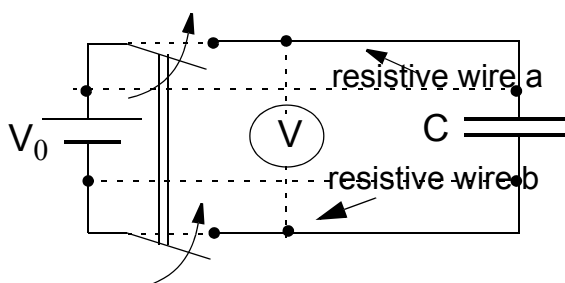
Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 9.



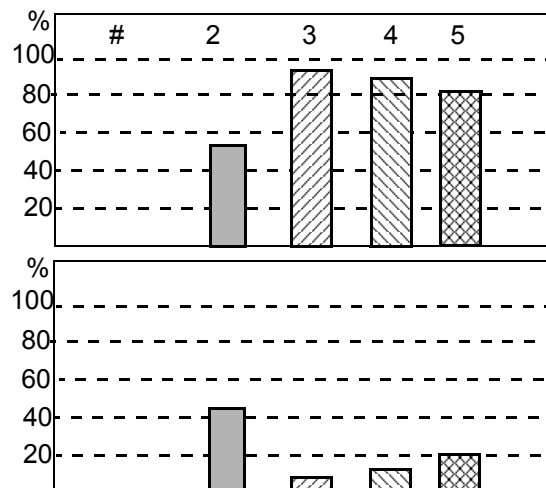
Question:

Where can the time-dependent voltage be measured?

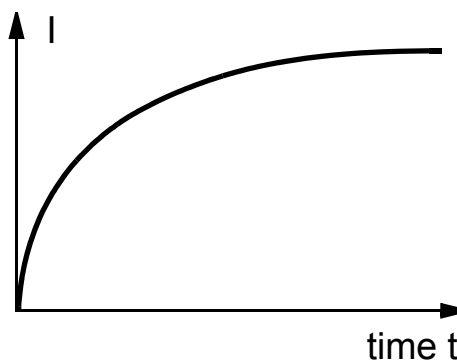
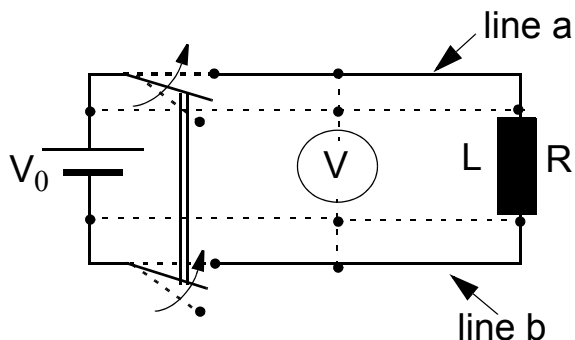
Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.

2) The problem is a rather specific one and physics students do not really have to know the correct answer.



To Assignment 10.

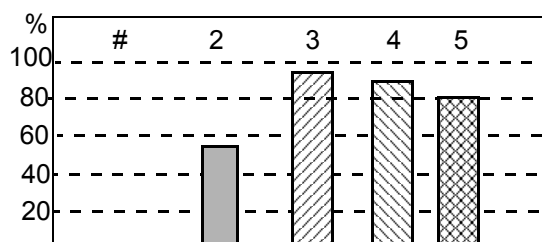


Question:

Where can the time depending voltage V be measured?

Which of the following statements corresponds with your opinion?

1) The problem is an important one and physics students should know the answer after having finished an electricity course.



2) The problem is a rather specific one and physics students do not really have to know the correct answer.

