EXPERIMENTAL COMPETITION

17 January, 2008

Please read the instructions first:

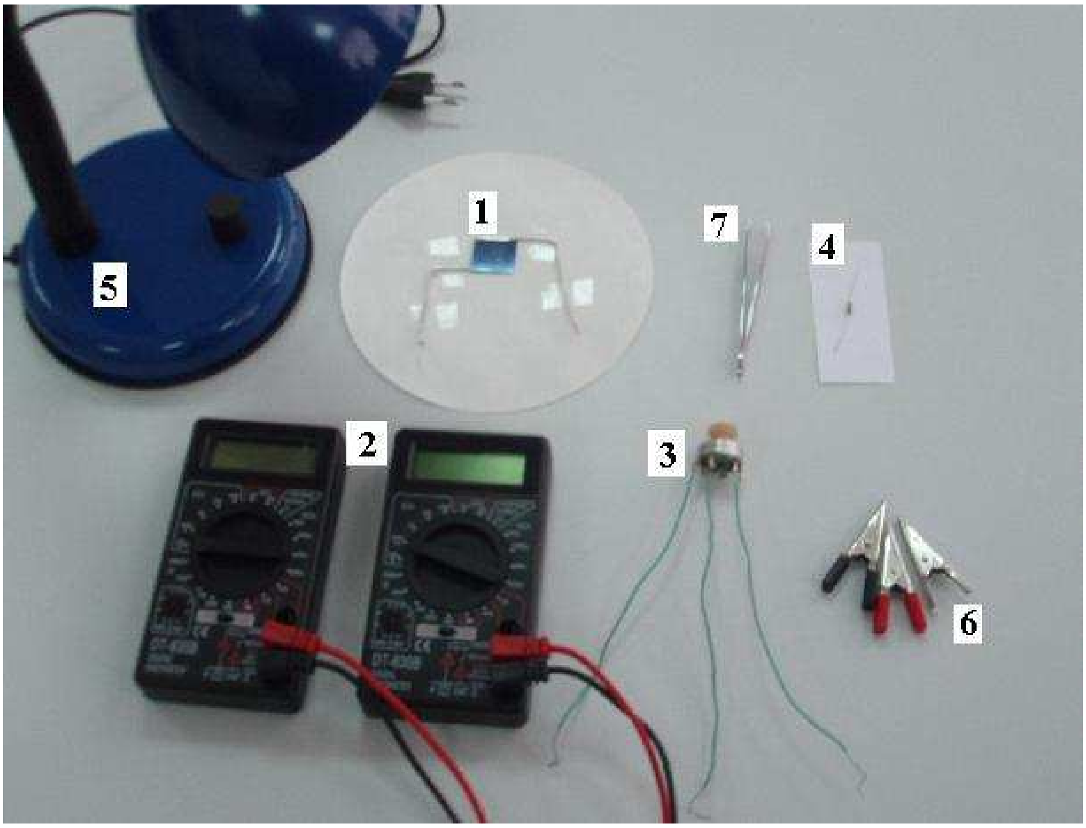
1. The Experimental part consists of one problem. This part of the competition lasts 3 hours.
2. Please only use the pen that will be given to you.
3. You can use your own non-programmable calculator for numerical calculations. If you don’t have one, please ask for it from Olympiad organizers.
4. You are provided with ***Writing sheet and additional papers***. You can use the additional paper for drafts of your solutions but these papers will not be checked. Your final solutions which will be evaluated should be on the ***Writing sheets***. Please use as little text as possible. You should mostly use equations, numbers, figures and plots.
5. Use only the front side of ***Writing sheets.*** Write only inside the bordered area.
6. Begin each question on a separate sheet.
7. Write on the blank ***writing sheets*** whatever you consider is required for the solution of the question.
8. Fill the boxes at the top of each sheet of paper with your country (***Country*)**, your student code (***Student Code***), the question number (***Question Number*)**, the progressive number of each sheet **(*Page Number***), and the total number of ***Writing sheets*** (***Total Number of Pages***). If you use some blank ***Writing sheets*** for notes that you do not wish to be evaluated, put a large X across the entire sheet and do not include it in your numbering.
9. At the end of the exam, arrange all sheets for each problem in the following order:
   - Used ***Writing sheets*** in order;
   - The sheets you do not wish to be evaluated
   - Unused sheets and the printed question.

   Place the papers inside the envelope and leave everything on your desk. You are not allowed to take any paper or equipment out of the room

Investigation of a solar cell

***Gadgets and materials**:* Solar cell (1), two digital multimeters (2), variable resistance (3), fixed resistance (1,00±0,01) Ohm (4), electric lamp (5), “alligator” clips (6), tweezers (7), 3 sheets of plotting paper(8).

Energy generation plays an important role in the life of the humankind. Renewable sources of energy have gained significance recently due to diminishing of the mineral energy resources of the Earth. Solar energy is one of the possible candidates. Research to manage this type of energy is being conducted in Kazakhstan. Solar cells directly convert solar energy into electricity. In this work you are asked to investigate certain properties of a solar cell. These cells have been manufactured for the Olympiad in the laboratory of opto- a microelectronics of Kazakh state university.



Attention: Solar cells are very fragile, please be very careful while dealing with them. You are not allowed to directly touch them. Their characteristics might change considerably due to contamination. Please use tweezers and "alligator" clips to connect them into a circuit. Position of the solar cell relative to the lamp should be fixed during the measurements. It is recommended to turn the electric lamp on only during the measurements. Please be careful, the surface of the lamp is hot.

The task for the experimental competition (15 points):

You need to measure the voltage-current characteristic of a solar cell. You can use multimeters ***only*** to measure the voltage (i.e. as voltmeters). Their usage to measure current (as amperemeters) leads to incorrect results, since their internal resistance is not negligible.

Illuminate the solar cell using the lamp. The lamp should be used at a maximal power, and located at a distance of 10-20 sm from the solar cell.

a) Directly measure the electromotive force (emf) of the solar cell. Provide a circuit used for the measurement. ***(1 point)***
b) Attach the external resistance to the solar cell using the variable resistance and fixed resitance. Measure the dependence of the current through the cell as a function of the voltage drop on the external resistance. Plot this dependence and provide a circuit used for the measurement. You can use multimeters ***only*** as voltmeters. ***(5 points)***
c) Assuming that for small currents emf and internal resistance of the solar cell are constant, determine their values using the data measured in part b). ***(3 points)***
d) Theoretically determine the external resistance for the source with constant internal resistance, for which the heat power dissipated in the external resistance is maximal. Using the result of part c), calculate theoretically this resistance assuming constant internal resistance of the solar cell. ***(1 point)***
e) Using the data obtained in part b) plot the dependence of the heat power dissipated in the external resistance as a function of the external resistance. Determine the value of the external resistance for which this heat power is maximal. What is the ratio between this resistance and the result of part d)? (***3 points)***

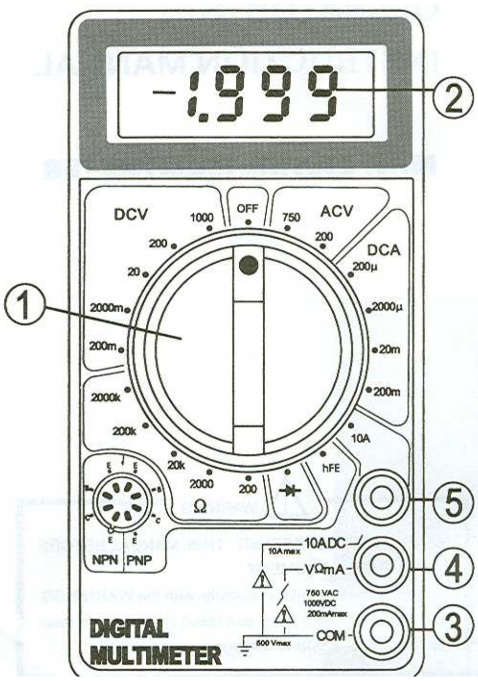
f) Filling coefficient is defined as the ratio of the maximal power dissipated in the external resistance to the product of the emf (measured in part a)) and maximal current through the solar cell. Determine the filling coefficient of the solar cell. ***(2 points)***

Appendix

INSTRUCTIONS FOR DIGITAL MULTIMETER

FRONT PANEL DESCRIPTION

1. FUNCTION AND RANGE SWITCH. This swish is used to select the function and desired range as well as to turn on the instrument. To extend the life of this battery, the switch should be in the “OFF” position when the instrument is not is use.
2. DISPLAY
3. “COMMON” JACK. Plug in connector for black (negative) test lead.
4. “VΩmA” JACK. Plug in connector for red (positive) test lead for all voltage and resistance and current (except 10 A) measurements.
5. “10 A” JACK. Plug in connector for red (positive) test lead for 10 A measurement.



DC VOLTAGE MEASUREMENT

1. Connect red test lead to “VΩmA” jack. Black lead to “COM” jack.
2. Set RANGE switch to desired DCV position. If the voltage to be measured is not known beforehand, set switch to the highest range and reduce it until satisfactory reading is obtained.
3. Connect test leads to device or circuit being measured.
4. Turn on power of the device or circuit being measured, voltage value will appear on Digital Display along with the voltage polarity.

AC VOLTAGE MEASUREMENT

1. Red lead to “VΩmA”. Black lead to “COM”.
2. RANGE switch to desired ACV position.
3. Connect test leads to device or circuit being tested.
4. Read voltage value on Digital Display.

DC CURRENT MEASUREMENT

1. Red lead to “VΩmA”. Black lead to “COM”. (For measurements between 200 mA and 10 A connect red lead to “10 A” jack with fully depressed.)
2. RANGE switch to desired DCA position.
3. Open the circuit to be measured, and connect test leads IN SERIES with the load in which current is to be measured.
4. Read current value on Digital Display.

RESISTANCE MEASUREMENT

1. Red lead to “VΩmA”. Black lead to “COM”.
2. RANGE switch to desired Ω position.
3. If the resistance being measured is connected to a circuit, turn off power and discharge all capacitors before measurement.
4. Connect test leads to circuit being measured.
5. Read resistance value on Digital Display.

STRAIGHT LINE FIT USING THE LEAST SQUARES METHOD

Be $y = ax + b$ the least squares regression fit obtained by this method. Then:

$$a = \frac{\sum_i^n x_i \sum_i^n y_i - n\sum_i^n x_i y_i}{\left(\sum_i^n x_i\right)^2 - n\sum_i^n x_i^2} \qquad b = \frac{\sum_i^n x_i \sum_i^n x_i y_i - \sum_i^n y_i \sum_i^n x_i^2}{\left(\sum_i^n x_i\right)^2 - n\sum_i^n x_i^2}$$

$$\Delta a = \sqrt{\frac{n\sigma^2}{n\sum_i^n x_i^2 - \left(\sum_i^n x_i\right)^2}} \qquad \Delta b = \sqrt{\frac{\sigma^2 \sum_i^n x_i^2}{n\sum_i^n x^2 - \left(\sum_i^n x_i\right)^2}}$$

σ can be given as $\sigma = \sqrt{\sigma_y^2 + a^2\sigma_x^2}$, with $\sigma_x = \sqrt{\frac{\sum_i^n \Delta x_i^2}{n}}$ and $\sigma_y = \sqrt{\frac{\sum_1^n \Delta y_i^2}{n}}$ where Δx_i and Δy_i are the individual uncertainties of the n independent measurements.