The automated laboratory complex with remote access «Molecule physics and thermodynamics»

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Abstract. It has been created the automated laboratory complex with remote access. It provides access for students to laboratory resources of the National Research University «MPEI» in the multi-user mode in real time. The automated remote laboratory complex provides the study of the theory and technique of experimental determination physical quantities; the execution of work in simulation mode; the remote execution of work at real equipment, acquisition and analyzing data, the estimation of students work results. At present time the four laboratory setups are available.

1. Introduction
The automated laboratory complex with remote access [1] is located on the Department of General Physics and Nuclear Fusion of the National Research University «MPEI». The control of the experiments are carried out distantly by web address http://dex.mpei.ru/ by students in a multi-user real-time mode using modular object-oriented dynamic learning environment (Moodle) [2]. The complex "Molecular physics and thermodynamics" is produced under the technology of industrial automatization. Measuring and control modules produced by the NPF «OVEN» are used. The control of the experiment is realized by web interface of LabVIEW virtual instrument.

The laboratory complex consists of five laboratory works of the theme «Molecular physics and thermodynamics»:
- determination of the air thermal conductivity by the hot-wire technique;
- determination of the specific heat capacity of air at constant pressure by the flow method;
- determination of the air heat capacities ratio;
- check of the Kelvin temperature scale (gas thermometer of constant volume);
- the specific heat of fusion of stannum determination (in the development).

The laboratory works are executed by a group of students by turn.

The main components of the remote laboratory system include [3] main server, remote training laboratory with automated laboratory setups, video channels of monitoring experiments, a computer class, the special software. The software is used for controlling devices of laboratory and data acquisition, analyzing experimental data, managing of remote users, estimating of work results and their accounting [4]. The server is based on OS Windows with additional program package for Web applications (Apache, MySQL, PHP, learning management system Moodle).
2. Description
The operation of the automated laboratory complex with remote access have been described, for example, of «Determination of the air heat capacities ratio» laboratory work.

The scheme of laboratory setup is shown in the figure 1a. The setup consists of the following main components: gas balloon 1 made of glass, fast-acting solenoid valve 2; compressor 3, designed to create an excess air pressure in the balloon 1; piezoelectric gauge 4, used to measure the excess air pressure in cylinder 1; solenoid valve 5 to disconnect the balloon 1 from the compressor 3. All processes occur with a certain mass of gas 6, mentally separated within the volume of the balloon and located far from the walls and the valve.

Figure 1. The scheme(a) and visual appearance (b) of laboratory setup.

In order to determination the air heat capacities ratio at the room temperature is used the method developed by Clément and Desormes. The setup is located in the standard unit (fig.1 б).

At first the air pressure in the cylinder is equal to atmospheric pressure, and the temperature is equal to the ambient temperature (point A in Figure 2).

While the pressure in the system is increased by means of a compressor, the certain volume of air 6 in the balloon (Fig. 1a) is compressed and its temperature becomes higher than the ambient temperature. Tentatively, this process can be represented on the pressure dependence of volume $p(V)$ as a dashed curve AB (Figure 2). After the solenoid valve 5 is automatically closed, the process of isochoric cooling of air takes place up to ambient temperature $T_0$ (process B-1). At the same time, the air pressure decreases, it is fixed by reducing the excess pressure in the system and reducing the temperature of the air in the balloon. This process goes on several minutes and will finish when the indications of the piezoelectric manometer are stabilized.

Point 1 in the pressure dependence of volume $p(V)$ corresponds to the initial state of system when the pressure $p_1$ is above atmospheric pressure and the temperature $T_1$ equals to the ambient temperature $T_0$ (room temperature). The excess pressure $p'$ and pressure difference $p''-p'$ are measured by the piezoelectric gauge and collected. The valve 2 shortly opens and automatically closes (valve opening time is 0.2 seconds) by pressing the button for controlling the valve 2. While the valve 2 is opened the adiabatic expansion of air takes place, process 1-2, (during this time the pressure is more than atmospheric pressure). The gas temperature decreases and the pressure also decreases. After closing the valve, the process of isochoric heating of air to room temperature $T_0$ begins, and the pressure starts to increase (process 2-3). The value of excess pressure $p''$ is measured when this process is over. The isochoric process 2-3 ends when the indications of the piezoelectric manometer are stabilized.

To remote control the laboratory setup, it is necessary to download the LabView RunTime module through the link "Required LabView module" on the page of the course "Thermodynamics and heat transfer". On the page of the e-learning course go to the link "Determination of the adiabatic exponent
of air, remote laboratory work. The control panel of the experimental setup is opened (Fig. 3.). There is a button "Pumping", it turns on the compressor. The air injection continues until the gauge value of the excess pressure on the upper indication field reaches (2000 - 2500) Pa. After that, the compressor is automatically turned off.

![Figure 3. Control panel of the experimental setup.](image)

The current state of experiment is shown in Fig. 3, for example. The gauge value of the excess pressure is 606.98 Pa. This indication is duplicated by the position of the horizontal line bounding the blue field with the scale of pressure. The measured temperature within the balloon equaling to 24.3 °C is shown on the bottom indication field. The valve 2 is controlled by the button «exhaust». The measured data are recorded in the table by pressing the button "Record the results in the table". After this the value of the adiabatic exponent is calculated and displayed. The experiment is over and is transmitted to another student.

It can be opened the web page with live stream of the front panels of laboratory setups. It allows monitoring the progress of experiments. A screenshot of this page is shown in fig. 4. The live stream is carried out with the help of IP cameras of models TrendNet TV-IP501w and TV-IP522p.

![Figure 4. A screenshot of page with a live stream.](image)

3. E-learning resource
The automated laboratory complex with remote access includes the e-learning resource of molecule physics and thermodynamics for students of schools and universities. The e-learning resource consists
of five interactive lectures of molecule physics and thermodynamics, descriptions of five laboratory works, computer models of laboratory works, remote access software. The automated remote laboratory complex provides the study of the theory and technique of experimental determination physical quantities; the execution of work in simulation mode (it doesn’t use real laboratory devices); the study of work order with real laboratory devices in the mode of remote access; admission to work after answering control questions; the execution of work and data acquisition; analyzing experimental data.

The e-learning resource corresponds to the conception of an automated laboratories with remote access developed at "MPEI" [1]. A list of available courses is displayed on the main page of the resource web site. Free access to the courses is allowed, so students can choose any one. After clicking the "Register for a course" button, only chosen course will be displayed on the main page of the site. Clicking the "All Courses" button is allowed to choose another course. Before execution of the laboratory work a student must study its description on the page «Introduction». Any one gets access to the laboratory work in simulation mode after reading the "Introduction" page and answering the test questions. It is necessary to get correct answers for three questions during 5 minutes. The simulation mode is allowed to study execution of real laboratory works. It can be done by infinite quality of students simultaneously.

Work windows of different laboratory works in the simulation mode are represented in figs. 5-8.
4. Results

The developed e-learning resource has been tested by students and school pupils at lectures and laboratory classes. It has shown animations from the e-learning resource to explain theoretical bases of these experimental works.

Laboratory work is carried out by students in a computer class. Those students who did not have time to do the work in the class can execute them at home, using a personal computer, according to the schedule of inclusion of the remote access laboratory, which is published on the e-learning resource website.

In the periods of September-November 2014 and September-November 2015 more than 50,000 visits of the e-learning resource were recorded over the Internet. More than 2,000 users worked with this e-learning resource.

The automated laboratory complex with remote access «Molecule physics and thermodynamics» is a logical continuation of the development of the laboratory complex of the General Physics course at the Department of Nuclear Physics of the National Research Institute "MPEI". Laboratory complex of the General Physics course contains about sixty laboratory works executed on real equipments (two-thirds of which can be done in the simulation mode).

The exhibit «The automated laboratory complex with remote access «Molecule physics and thermodynamics» was presented at the 16th All-Russian Forum «Educational Environment» (2014, Moscow, VDNH). As a result of the competition, the exhibit was awarded the medal "Laureate of All-Russia Exhibition Center".

5. References

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