CREATIVE LABORATORY EXPERIMENTS FOR BASIC PHYSICS USING COMPUTER DATA COLLECTION AND EVALUATION EXEMPLIFIED ON THE INTELLIGENT SCHOOL EXPERIMENTAL SYSTEM (ISES)

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Abstract - *A new type of physics laboratory for non-major undergraduate students is presented, fully computerized as far as the following activities are concerned: instructions as interactive web pages, data collection, evaluation, modeling or simulation and report presentation. The major accent is on the examination of real world phenomena and their physical background. Throughout the laboratory the Intelligent School Experimental System (ISES – Charles University in Prague) is widely used. The results achieved are demonstrated on the measurements, on the example of the measurement of the geometrical dimensions of micro objects by physical optics diffraction, extended to the quantum physics Heisenberg principle of uncertainty, further, magnetic field mapping of the coils in the Helmholtz arrangement and, last, the change of state of the real gas.*

Key Words *– basic physic laboratory, non-major undergraduates, computer oriented, data collection, evaluation and modeling*

INTRODUCTION

The teaching of physics for a non - major undergraduate student in physics at technical universities has to challenge some very expressed dangers. The most obvious one stems from the perceived necessity to use analytical techniques in the teaching of nearly all aspects of physics had resulted, in the past, in syllabi that focus upon the study of artificially idealized systems that are rarely met in the real applications. A serious consequence is that it may give the student the impression that physics is a dead or dying subject. Nothing could be further from the truth if we realize the recent potential progress, the computers have brought in teaching of real - world physics [1].

The second circumstance forcing the computers in laboratory exercise of physics at the technical universities is that the experimental equipment used in a real industrial and research laboratory, where the student takes up employment after leaving the university, is nearly universally computerized.

This trend is obvious in all forms of teaching physics and the computers found their way gradually into modeling and simulations, computer aided lecturing and instruction, and only recently in data collection and their evaluation [1]. This latter fact was conditioned by the fact, that the demands on both software and hardware in physics laboratory are enormous in order to meet the basic requirements. But as the computers have progressed dramatically in the past ten years or so both as to hardware and software, this obstacle has been removed and computers found their way in the majority of laboratory exercises of physics undergraduate courses.

This paper describes gained experience connected with the introduction of the computer-oriented laboratory. The problem is exemplified on the utilization of the Intelligent School Experimental System (ISES [3][4]) interface and software and it is shown, how this system optimizes the above-mentioned compromise and criteria. The results achieved are demonstrated on the example of the measurement of the geometrical dimensions of micro objects by physical optics diffraction, extended to the quantum physics Heisenberg principle of uncertainty, further, magnetic field mapping of the coils in the Helmholtz arrangement and, last, the change of state of the real gas

The major obstacle for computer introduction into physics laboratory has been the fact that computers were perceived to be too complex and difficult to use and that they make the laboratory mysterious and so weaken the connection between reality and any results that are obtained [2]. Requirements for the computer oriented laboratory hardware and software for the basic physics course may be thus formulated:

- The system should be versatile, as to enable the creating of the simple measuring systems without inclusion of extra instruments both for signals generation and detection, enabling the interfacing, addressing and range selection,
- The system should record data in an economical and creative fashion. The requirement of the data recording is the most stringent as the collected data should be easily processed with arbitrary graphical or data processing program. On the other hand the strict requirement for the creative approach forces the choice of the open system of the module type,
- The measuring system has to provide an easy accessible real-time data processing together with graphical displays to enable the fast feedback for the student to support his or her creative approach,
- The measuring system should enable the inclusion of the procedures enabling the evaluation of results taken from a

conventional laboratory experiment - approximation by a preselected function, statistical and least squares fitting of curves and straight lines and similar,
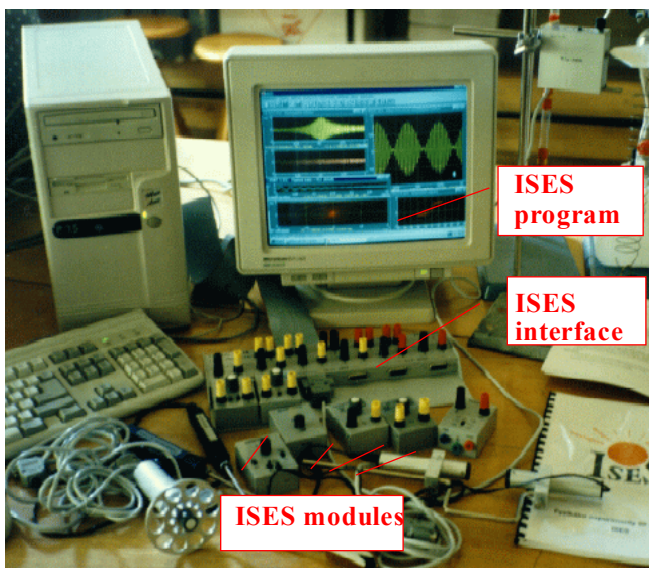
- The student must have the possibility of the interactive control of the experiment and continuous on-line data analysis enabling to continuously compute and update the results and to decide if the precision just obtained is sufficient,

- For the obvious reasons of a short allocated time for the physics laboratory exercise and the necessity of the focusing on thy phenomenological side of the problem it is not reasonable to make any programming during the exercise.

The above formulated requirements for the data collecting and evaluating system are rather strict, so the choice for the application was the measuring systems CASSY (Leybold Didactic), IP - COACH, PHYWE - COBRA and ISES (Charles University in Prague. The choice was the last one, so we intend to present briefly this system and show examples of its use in a real teaching process.

INTELLIGENT SCHOOL EXPERIMENTAL SYSTEM (ISES)

ISES is a teaching experimental system with computer as an example of teach ware - complex project for teaching of experimental and laboratory techniques. Its advantage is the diversity of sensing units, versatility, original conception and also low price. It is an open system working under WINDOWS (WIN 3.11, WIN 95, WIN NT, WIN 2000 and WIN XP) with all their advantages (OLE and multitasking). The system is composed of the interface card, set of variable modules and sensing elements and service program (see Figure 1).
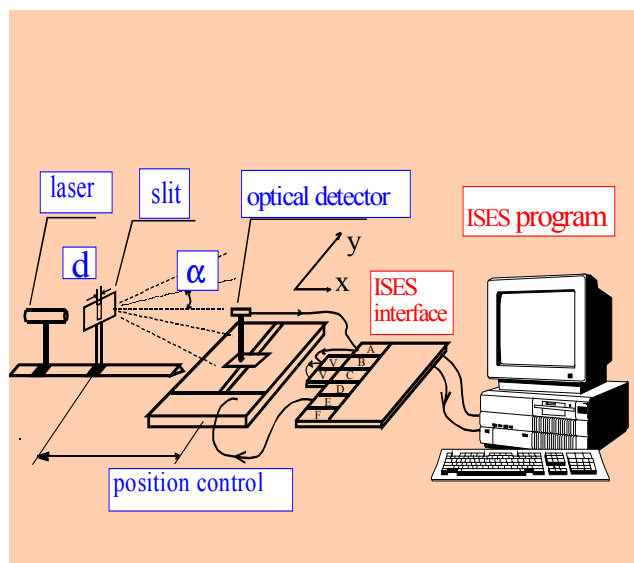
to arbitrarily any PC IBM compatible computer. We work in a wide range of computers. The card is the 12 bit ADDA, sample and hold and timer with maximum sampling frequency of 63 kHz.

The ISES modules are easily interchangeable, their presence and adjusted range is automatically sensed by the computer, with the automatic calibration facility. The system is equipped with the following modules (constantly amended list): voltage (10V - 5mV), current (1A - 0.5mA), resistance, capacitance, temperature (-20°C÷+120 ^{o}C), light microphone, deviation sensing unit, adjustable preamplifier, light stop, current booster, relay switch, pressure meter and many others. The service program enables to measure simultaneously 10 different channels (8 analog and 2 binary) and to use 4 programmable outputs channels. All these are fully programmable, using the programming panel.

GEOMETRICAL DIMENSIONS OF MICROOBJECTS STUDIED BY ISES

The task of the exercise is to measure the dimensions of micro objects using the evaluation of the diffraction pattern of coherent light from laser source. The arrangement for the measurement of the width of the slit by the diffraction of the laser is seen in Figure 2, where we used the experimental set consisting of the laser illuminating the slit. The diffracted light is picked up by the photo diode light detector, attached to the movable X-Y plotter pen holder. Both light detector and X-Y plotter are interfaced to the ISES, so that the whole diffraction pattern can be detected. To support the creativity, we encourage the student to arrange the settings of the data collection as the distance of the slit to the
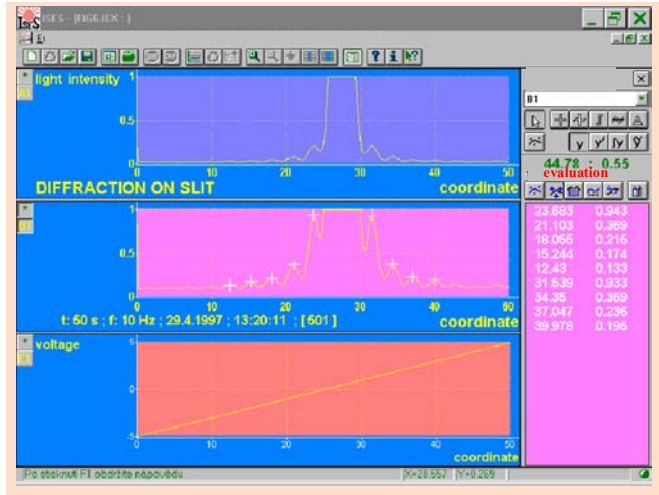
FIGURE1
" ISES"-INTELIGENT SCHOOL EXPERIMETNAL SYSTEM

The computer interface card with the inputs and outputs and plug in slots for modules provides the easy way of interfacing

FIGURE 2
ARRANGEMENT OF THE DIFFRACTION EXPERIMENT WITH **ISES** SERVING AS CONTROL AND DATA COLLECTION UNIT

FIGURE 3
THE DIFFRACTION PATTERN TAKEN FROM THE SLIT OF THE WIDTH d=180 μm WITH DIFFERENT SENSITIVITIES OF THE PREAMPLIFIER THE MAXIMA ARE DIGITIZED - SEE PRINTOUT

screen, the rate of the scanning of the diffraction pattern, the sampling rate of the data collection and the sensitivity of the preamplifiers. The results of a student experiment taken by the ISES are in Figure 3.

The diffraction intensity distribution $I(\alpha)$ of the single slit is described by the Frauenhofer diffraction formula

$$I(\alpha) = I(O)\left(\frac{\sin \beta}{\beta}\right)^2, \quad \beta = \frac{\pi d}{\lambda} \sin \alpha, \qquad (1)$$

where d is the sought width, α is the diffraction angle (tgα= y/b, here y is the position on the screen and b is the distance of the screen from the diffraction slit) and λ is the wavelength. In further procedure, we let the student to decide, how to evaluate the results. The easiest way to use is to the positions of the maxima (minima) of the function (1) and to fit the sought width d of the slit. There is another possibility, namely of the fitting the measured dependence as a whole to (1) by the fitting procedure. For this we use the non-linear programming in Jandel SIGMA PLOT 5.0 for fitting the measured data to the model equation. The graphical results of the fitting procedure are in Figure 4. The results of both approaches are summarized in Table. It is obvious that the errors decreased by the fitting by more then one order of magnitude.
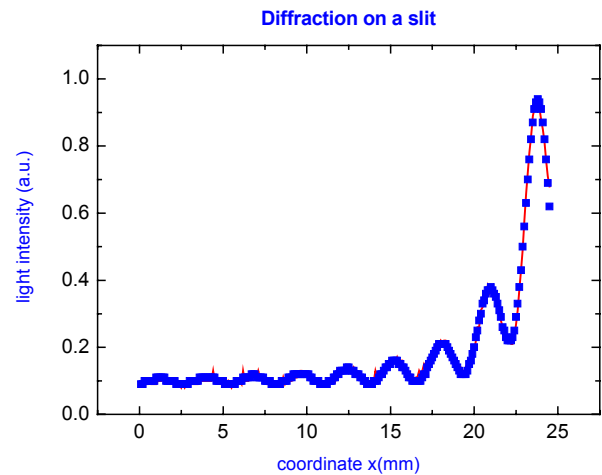
Verification of quantum physics Heisenberg principle of uncertainty

The Heisenberg uncertainty principle expresses the impossibility of the determination simultaneously the position y and corresponding momentum p_y of a micro particle (photon) with infinite certainty, but their uncertainty are bound by

$$\Delta y \, \Delta p_y \geq \frac{h}{2\pi}, \qquad (2)$$

FIGURE 4
THE DIFFRACTION PATTERN TAKEN FROM THE SLIT OF THE DIMENSION d=180 μm (POINTS) AND THE NUMERICAL FITTING BY NON-LINEAR PROGRAMMIN USING (1) (RED BOLD CURVE)


TABLE

No	maxima/minima	Fitting to (1)
1	$d_1 = (250 \pm 20)$ μm	$d_1 = (247.1 \pm 0.5)$ μm
2	$d_2 = (130 \pm 10)$ μm	$d_2 = (128.2 \pm 0.3)$ μm
3	$d_3 = (170 \pm 10)$ μm	$d_3 = (168.6 \pm 0.4)$ μm
4	$d_4 = (210 \pm 20)$ μm	$d_4 = (212.6 \pm 0.8)$ μm

where h = $6.6262.10^{-34}$ Js is Planck constant. This may be verified using the diffraction experiment arrangement. If we consider the measuring process of the position of a photon its passage through the slit with width d , then the corresponding uncertainty of the position is $\Delta y = d$. The corresponding uncertainty of the momentum Δp_y may be determined from the position of the first diffraction minimum (see Figure 5), i.e

$$\Delta p_y = m_{ph} c \sin(a_{\min}). \qquad (3)$$

FIGURE 5
THE DIFFRACTION OF A PHOTON ON A SLIT OF THE WIDTH d
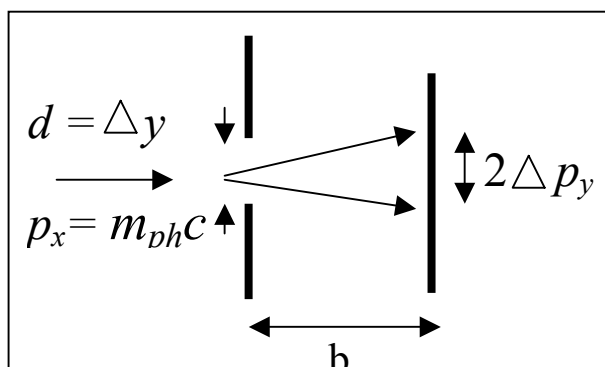
After slight rearrangements we obtain

$$\frac{d}{\lambda}\sin(arctg\frac{\alpha_{min}}{b}) = 1 \qquad (4)$$

If the Heisenberg principle of uncertainty is valid, then (4) should be experimentally verified. The students are encouraged to test (4) by changing the slit dimensions.

MAGNETIC FIELD MAPPING

A method of spatial distribution of the magnetic field induction of a pair of coils in the Helmholtz arrangement is presented. The experimental apparatus consists of an experimental object
and measuring system ISES supported by a computer. The main problem was to pick up the magnetic field induction in a selected point as a vector quantity. The principle of magnetic field vector detection is based on the Faraday's law of induction. The induced electromotive force ε in the measuring coil when the magnetic flux Φ is changed, is

$$\varepsilon = -\frac{d\Phi}{dt}. \qquad (5)$$

From (5) the magnetic field induction B perpendicular to the plane of the coil is proportional to the integral of the measured electromotive force $\varepsilon(t)$

$$B = \frac{1}{NS}\int_0^\infty \varepsilon(t)dt, \qquad (6)$$

where S is the area of the coil, N is the number of turns of the coil and R is its resistance. For the detecting of the magnetic field inductance vector **B** we need in principle three independent information concerning three perpendicular components, B_x B_y and B_z. For this purpose, three coils, perpendicular to each other, wounded on a cube, give such a point vector detector. The vector detector of the magnetic field inductance is in Figure 6. In our arrangement the system

FIGURE 6
THE VECTOR DETECTOR OF THE MAGNETIC FIELD INDUCTRANCE
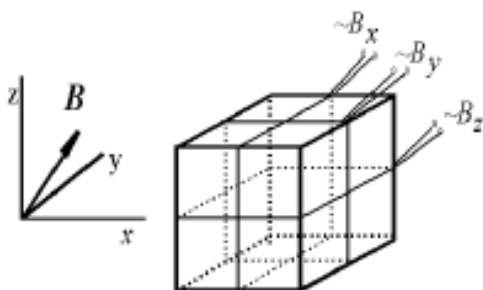
consists of three perpendicular measuring coils fixed on the arm of the goniometer. The control program of ISES generates the rectangular current pulses for the Helmholtz's coils supply and corresponding electromotive force is generated in the

three coils of the vector detector (Figure 7. with only two signals, for clarity)

FIGURE7
THE CURRENT PULSES (RED CURVE) AND TWO ELECTROMOTIVE VOLTAGES IN TWO PERPENDICULAR COILS OF THE VECTOR DETECTOR(GREEN AND BLUE CURVES)
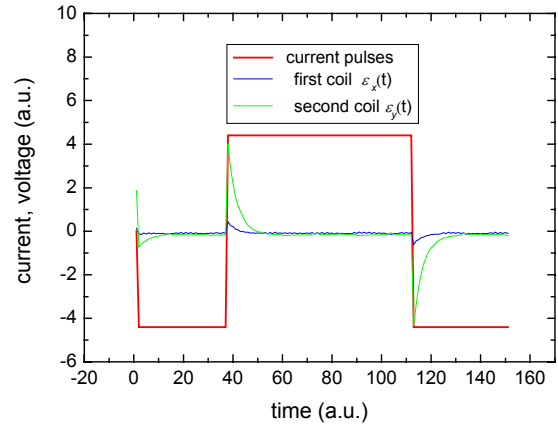
The electromotive force signal ε and its s integral $\int \varepsilon(t)dt$ (performed by ISES) is proportional, according to (6), the resulting magnetic field inductance component. The software of ISES enables storing the data and depicting the spatial variation of magnetic field (Figure 8).

FIGURE 8
THE VECTOR REPRESENTATION (IN TWO DIMENSIONS) OF THE SPATIAL CHANGES OF THE MAGNETIC FIELD INDUCTANCE
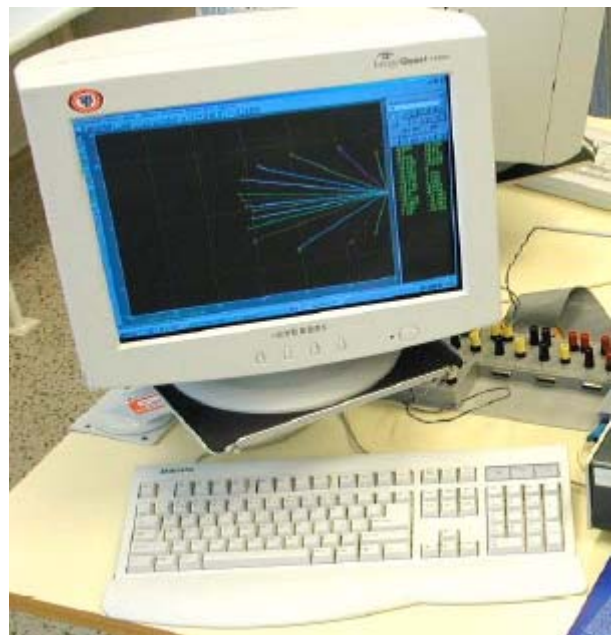
CHANGE OF STATE OF THE REAL GAS

The adiabatic change occurs when no exchange of energy between examined gas and the surrounding exists. It is rather difficult condition to fulfil in a real experiment. One way is to carry out the change quickly enough so the energy exchange could be neglected. An experimental apparatus for such school laboratory experiment was developed on the basis of ISES system. The equipment (Figure 9) consists of a 50 ml cylindrical vessel with piston in a stand for a hand drill. It enables to press the gas inside the cylinder in 0.1 s. The movement of the piston (volume change) is scanned by a slide potentiometer and module ohmmeter. The pressure is picked up by the module barometer and the temperature is measured by the thin thermocouple (wire of 0.05 mm in diameter) inside the cylinder and by the module voltmeter.The response of state variables is recorded and displayed on the monitor of the supporting computer (Figure 10). The upper trace is the pressure change; the middle one is the volume record and the bottom one shows the temperature development. The scales and sampling frequency are adjusted so that some tens of points in region of adiabatic change can be plotted. The measured data can be easily exported into Excel for further processing.

FIGURE 9

THE EXPERIMENTAL SETUP FOR THE MEASUREMENT OF THE CHANGE OF THE STATE OF THE REAL GAS

FIGURE 10

THE STATE QUANTITIES OF THE REAL GAS DURING THE CHANGE OF THE STATE OF THE REAL GAS: UPPER TRACE (GAS PRESSURE), THE MIDDLE TRACE (VOLUME) AND THE BOTTOM (TEMPERTURE)
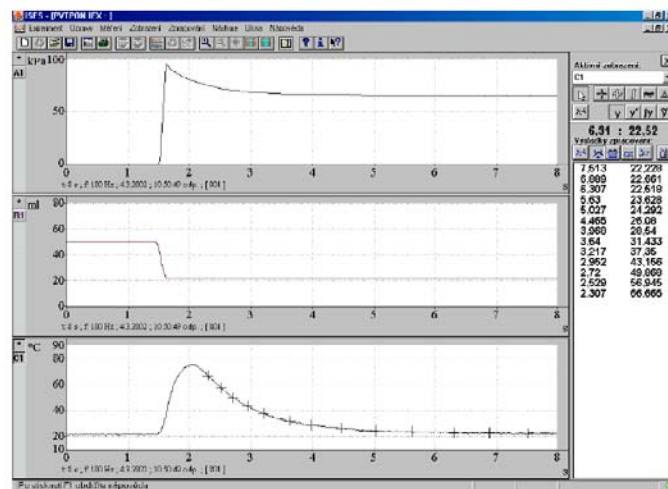
LABORATORY EXPERIMENTS FOR NON MAJOR UNDERGRADUATE STUDENTS

The two semester course of physics laboratory is distributed into four blocks,
1. Mechanical and thermal properties
2. Electric and non-electric properties,
3. Oscillations, waves and optics,
4. The measurement of microphysical phenomena,
covering 24 unique laboratory exercises. In all these experiments the data collection are computerized, mostly by ISES. The students are encouraged to model the measured phenomena and compare with the measured results. The report, prepared in laboratory on the computer, is obligatory.

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FIGURE 11
CREATIVE LABORATORY FOR BASIC PHYSICS WITH COMPUTER DATA COLLECTION EVALUATION AND MODELLING WITH INTELLIGENT SCHOOL EXPERIMENTAL SYSTEM (ISES), 12+1 PC NETWORKED WORKING PLACES, CONNECTED TO WWW, POSSIBILITY OF MULTIPLEXING OF STUDENTS WORKING PLACES BY THE TEACHER