Chapter 26

Creative Laboratory Experiments for Basic Physics Using Computer Data Collection and Evaluation Exemplified with the Intelligent School Experimental System (ISES)

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A new type of physics laboratory for non-major undergraduate students is presented. Ths laboratory is 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 focus 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 with the measurement of the geometrical dimensions of micro objects by physical optics diffraction, extended to Heisenberg principle of uncertainty in quantum physics; magnetic field mapping of the coils in the Helmholtz arrangement; and the change of state of a real gas.

INTRODUCTION

The teaching of physics for non-major undergraduate students in physics at technical universities has to face some well-recognized challenges. The most obvious challenge stems from the perceived necessity to use analytical techniques in the teaching of nearly

all aspects of physics. In the past this resulted in in syllabi that focused upon the study of artificially idealized systems that were rarely faced in 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 observe recent potential progress that computers have brought in the teaching of real-world physics [1].

The second circumstance forcing the use of computers in laboratory exercises of physics at technical universities is the near universal computerization of experimental equipment used in a real industrial and research laboratory, where the student takes up employment after leaving the university.

This trend is obvious in all forms of teaching physics. Computers have found their way gradually into modeling and simulations, computer aided lecturing and instruction [2-4] and, recently, in data collection and their evaluation [5]. This latter trend was conditioned by the enormous demands on both software and hardware in physics laboratory in order to meet basic requirements. But as computers have progressed dramatically in the past ten years or so – both hardware and software – this obstacle has been removed and computers have found their way into the majority of laboratory exercises of physics undergraduate courses.

This paper describes the experience gained with the introduction of a computer-oriented laboratory. The problem is exemplified with the Intelligent School Experimental System (ISES) [6] interface and software and it is shown how this system optimizes the above-mentioned compromise and criteria. The results achieved are demonstrated by the example of measuring the geometrical dimensions of micro objects by physical optics diffraction, extended to the quantum physics Heisenberg principle of uncertainty; magnetic field mapping of the coils in the Helmholtz arrangement; and, the change of state of a real gas.

The major obstacle for computer introduction into the physics laboratory has been the fact that computers were perceived to be too complex and difficult to use and that they made the laboratory mysterious and therefore weakened the connection between reality and any results that were obtained [5]. Requirements for computer oriented laboratory hardware and software for the basic physics course may be thus formulated as follows:

- The system should be versatile enough to enable the creation of simple measuring systems without the inclusion of extra instruments 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 an arbitrary graphical or data processing program. On the other hand, the strict requirement for creative approach forces the choice of the open system of the module type.
- The measuring system has to provide easily accessible real-time data processing, together with graphical displays to enable fast feedback for the student to support his or her creative approach.
- The measuring system should enable the inclusion of procedures for 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 interactive control of the experiment and continuous on-line data analysis enabling him/her 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 focusing on the phenomenological side of the problem it is not reasonable to make any programming during the exercise.

The above formulated requirements for 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). All the systems are more or less equivalent, and our choice was the last one, due to its accessibility (10 sets). We intend to present briefly this system and show examples of its use in real teaching process.

INTELLIGENT SCHOOL EXPERIMENTAL SYSTEM (ISES)

ISES is an experimental teaching system and an example of a teach-ware for the teaching of experimental and laboratory techniques. Its advantage is the diversity of sensing units, versatility, innovative concept, and low price. It is an open system working with 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 an interface card, a set of variable modules and sensing elements, and graphical interface and evaluation program (see Figure 1).

The computer interface card, with the inputs and outputs and plug-in slots for modules, provides an easy way of interfacing with virtually any PC IBM compatible computer. The card is the 12-bit ADDA, sample and hold and timer with a maximum sampling frequency of 63 kHz.

The ISES modules are easily interchangeable. Their presence and adjusted range are automatically sensed by the computer with the automatic calibration facility. The system is equipped with modules for the following (constantly amended list): voltage ($\pm 10V$ - 5mV), current (0.5mA $\div$1A), resistance, capacitance, temperature (-20°C to +120 ^{o}C), light microphone, deviation sensing unit, adjustable preamplifier, light stop, current
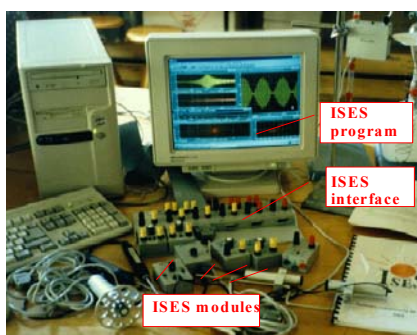

FIGURE 1
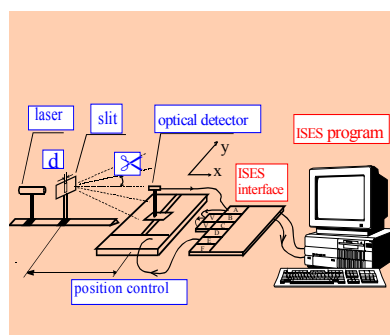ISES®-INTELLIGENT SCHOOL EXPERIMENTAL SYSTEM

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

booster, relay switch, pressure meter and many others. The service program enables the simultaneous measurement in 10 different channels (8 analog and 2 binary) and the usage of 4 programmable output channels. All options are fully programmable, using the programming panel.

GEOMETRICAL DIMENSIONS OF MICRO OBJECTS 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 a 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 a laser to illuminate the slit. The photo diode light detector, attached to the movable X-Y plotter penholder, picks up the diffracted light. Both the light detector and X-Y plotter are interfaced to ISES, so that the whole diffraction pattern can be detected. To support creativity, we encourage the student to use as settings for the data collection the distance of the slit to the 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 measured by ISES are presented in Figure 3.

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

$$I(\alpha) = I(0)\left(\frac{\sin\beta}{\beta}\right)^2, \quad \beta = \frac{\pi d}{\lambda}\sin\alpha, \qquad (1)$$

where d is the sought width, α is the diffraction angle (tgα= y/b, y is the position on the screen, and b is the distance of the screen from the diffraction slit) and λ is the wavelength. We let the student decide how to evaluate the results. The easiest way to do this is to take the positions of the maxima (minima) of the function given by Equation (1) and to fit the sought width d of the slit. There is another possibility, namely fitting the measured dependence as a whole to Equation (1) by the fitting procedure.
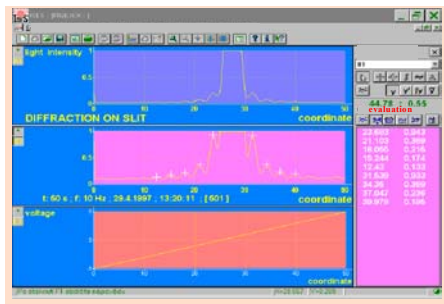

FIGURE 3
THE DIFFRACTION PATTERN TAKEN FROM THE SLIT OF THE WIDTH d=180 μm WITH DIFFERENT SENSITIVITIES OF THE PREAMPLIFIER. THE MAXIMA ARE DIGITIZED (PRINTOUT)
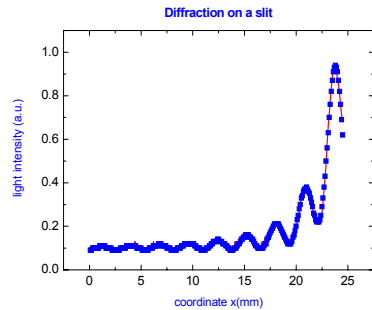

FIGURE 4
THE DIFFRACTION PATTERN TAKEN FROM THE SLIT FOR DIMENSION d=180 μm (SYMBOLS) AND THE NUMERICAL FITTING BY NON-LINEAR PROGRAMMING USING (1) (CURVE)

No	maxima/minima	Fitting to Equation (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	$d_4 = (212.6 \pm 0.8)$:m

TABLE 1

RESULTS OF THE DIMENSIONS OF MICRO OBJECTS MEASUREMENT

For this we used 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 shown in Figure 4. The results of both approaches are summarized in Table 1. It is obvious that errors decreased by more than one order of magnitude due to the fitting.

Verification of Heisenberg Principle of Uncertainty

The Heisenberg Uncertainty Principle expresses the impossibility of determining simultaneously the position y, and corresponding momentum p_y, of a micro particle (photon) with infinite certainty. Their uncertainties are bound by

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

where $h = 6.6262 \times 10^{-34}$ Js is the Planck constant. This may be verified using the diffraction experiment arrangement. If we consider the measuring process of the position of a photon in its passage through a slit with the width d, then the corresponding uncertainty of the position is $\Delta y = d$. The corresponding uncertainty of the momentum may be determined from the position of the first diffraction minimum (see Figure 5), i.e

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

After slight rearrangements, we obtain

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

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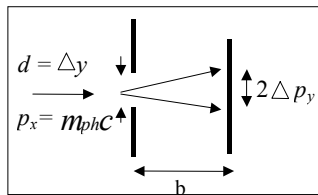

FIGURE 5

THE DIFFRACTION OF A PHOTON ON A SLIT OF THE WIDTH d

MAGNETIC FIELD MAPPING

A method of measuring the spatial distribution of the magnetic field induction of a pair of coils in the Helmholtz arrangement is presented. 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 Faraday's law of induction in a coil exposed to a changing magnetic field. The induced electromotive
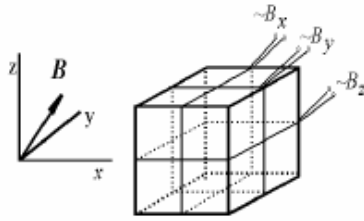
FIGURE 6

THE VECTOR DETECTOR OF THE
MAGNETIC FIELD INDUCTRANCE

force ε in the measuring coil with the magnetic flux Φ is

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

From Equation (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 and N is the number of turns of the coil. For the detection of the magnetic field inductance vector $\boldsymbol{B}$, we need in principle three independent values concerning three perpendicular components, B_x B_y and B_z. For this purpose, three coils, perpendicular to each other, wound on a miniature cube, function as such a point vector detector (Figure 6). In our arrangement the system, the electromotive force signal ε (see Figure 7) and its integral $\int\varepsilon(t)dt$ (performed by ISES) are proportional according to (6), the resulting magnetic field inductance component. The software of ISES enables storing the data and depicting the spatial variation of the magnetic field (Figure 8).

CHANGE OF STATE OF A REAL GAS

Adiabatic change occurs when no exchange of energy between an examined gas and the surroundings takes place. It is a rather difficult condition to fulfil in a real experiment. One way to do it is to carry out the change quickly enough so the energy exchange could be neglected. On the other hand, an isothermal process may be carried out by moving a piston very slowly in a piston-cylinder system so that the temperature remains nearly constant. The isochoric process may then be observed after adiabatic compression, when the piston is kept in a stable position. An experimental apparatus for such a school laboratory experiment was developed on the basis of the ISES system. The equipment
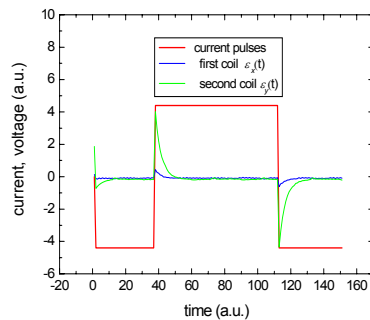

FIGURE 7

THE CURRENT PULSES (RED CURVE) AND TWO
ELECTROMOTIVE VOLTAGES IN TWO
PERPENDICULAR COILS OF THE VECTOR
DETECTOR (GREEN AND BLUE CURVES)

FIGURE 8

THE VECTOR REPRESENTATION (IN TWO
DIMENSIONS) OF THE SPATIAL CHANGES OF THE
MAGNETIC FIELD INDUCTANCE

FIGURE 9

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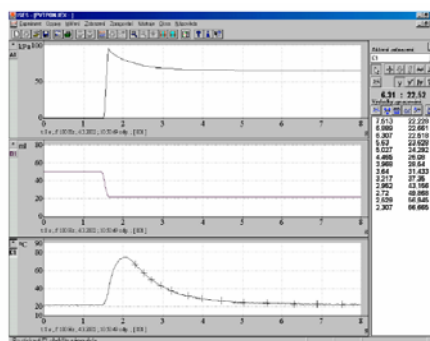

FIGURE 10

THE STATE QUANTITIES OF REAL GAS DURING THE CHANGE OF STATE OF REAL GAS: GAS PRESSURE (UPPER TRACE) , VOLUME (MIDDLE TRACE) AND TEMPERATURE (BOTTOM)

(Figure 9) consists of a 50 ml cylindrical vessel with a piston in a stand for a hand drill. It is possible to compress 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 module barometer picks up the pressure and the temperature is measured by the thin thermocouple (with wires of 0.05 mm diameter) inside the cylinder and by the ISES module voltmeter. The response of the 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 dozens of points in the region of adiabatic change can be plotted. The measured data can be easily exported into Excel for further processing.

CONCLUSIONS

The main conclusions may be stated as follows:

- The two-semester course of an introductory physics laboratory was built and oriented toward mechanical and thermal properties, electric and non-electric properties, ocillations, waves and optics, and microphysical phenomena, covering 24 unique laboratory exercises.
- In all these experiments the data collection was computerized, mostly by ISES.
- The students were encouraged to model the measured phenomena and compare with the measured results. A report, prepared in the laboratory on the computer, was mandatory.
- Though the didactic evaluation concerning the achievements of students in this type of new laboratory has not been carried out, the unanimous perception by teachers is that there is obvious increase in the level of knowledge and motivation for physics study in general by students. Also, in the questionnaire at the end of two subsequent courses, the students marked laboratory exercises as the most useful among all physics courses.
- Students appreciated the predominant advantage of the computer-oriented laboratory in enhancing skills and experience, when computers are used as

measuring instruments because, in principle, they (students) were able to measure, evaluate, and at least start a written report within three teaching units (about 150 mins).

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