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Development of a Cheap Data Acquisition System and the Application to School Science

Naw Moe Pwint Phyu*
Kiyoshi Takeda**

安価なデータ収集システムの開発とその理科教育への応用

ノー・モー・プウェン・ピュー*
武田　清**

安価な市販のADコンバータを利用したデータ収集システムを開発し，学校理科の実験への応用を試みた。このデータ収集システムは，Windowsパソコンと自作のオペアンプ回路，および英国Pico Techlonogies製ADC-11型ADコンバータを組み合わせたものである。この測定系を用いて，音さ，バイオリンおよびピアノの音波の波形の可視化と，熱電対を用いた高分解能温度測定による溶解熱測定を行った。いずれも学校理科の実験への応用として充分な精度を持つことがわかった。

〔キーワード：データ収集システム，理科教育，理科実験，音波，溶解熱〕

I. Introduction

Computer technology with its information processing abilities integrates all aspects of the scientific process model. Along with the development in information technologies (IT), it is strongly expected to carry out efficient IT education in the classroom. Especially because for the developing countries IT is one of the most important keyword for the growth of industries of their own, it is highly desired to prepare IT educational system at school.

The computer has numerous and diverse uses in the science classroom: (1) as an interactive teaching tool performing and directing simulations and addressing problem solving strategies, (2) as an information manager with database, (3) as a laboratory tool for collecting data. For the former two usages the development of contents including how to show them should be challenging. On the other hand, the last one includes the problem how to provide hardware as the form ready to use.

For use of computer as laboratory tool, it becomes a piece of laboratory equipment; sensitive devices or instruments which collect the various data are interfaced to the computer which records the data for use by the student. This type of scientific experimentation allows the student to use the same kinds of inquiry and problem solving strategies that practicing scientists use, but which has been difficult because of the cost of the highly specialized instrumentation. Another benefit of the computer based laboratory is the ability of the computer to continue to gather data over time, something not feasible for students typically limited to science lab. Using the computer as laboratory tool has an advantage over on-screen computer simulation in that it is using real data from the natural world.

The PC based data acquisition lessons are being taken parts in the science curriculum in these days.[1,2] However, most of the measurement systems are still too expensive to use in all schools. It is desired to be developed for a cheaper system that is available in any kinds of school. In this paper we report a data-acquisition system using a cheap medium speed analog to digital (AD) converter adoptable of PC measurement for school science though it does not provide very high precision. At a cost of cheapness, some simple circuit had to be constructed to complete the system. For use with this device, a voltage amplifier has been newly designed

* In-Service Teacher Training Course（教員研修留学生）
** Faculty of Natural Science Education（自然系（理科）教育講座）

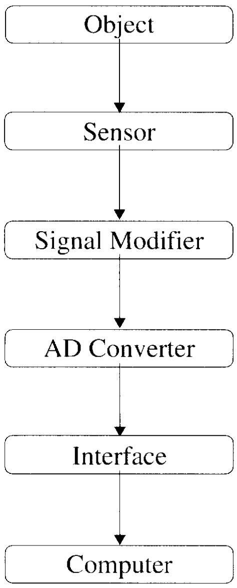

Fig.1. Schematic drawing of general data acquisition system.

to obtain a signal suitable for input of the AD converter. Finally, to test the performance, the system was applied for some science experiments.

Ⅱ. Construction of Data Acquisition System

General Description

Data acquisition process is the one that a natural physical quantity is taken into a personal computer as numerical data.[3,4] Figure 1 is a block diagram of the general data acquisition system. One kind of physical property of the object is detected by a sensor, which outputs electrical signal as a function of the property. Electrical signal from the sensor is modified to voltage suitable for the input of AD converter. In AD converter the signal is transformed to a digital value and output to the computer through the interface.

Sensor

Various kinds of devices are available as sensor dependent on the physical properties wanted to measure. For example, a photocell, a CdS sensor or a photoelectron multiplier is available for measurement of optical strength. These sensors output signal as voltage, resistance or number of electrical pulse as a function of illumination. Since each device has advantages and disadvantages of their own, the most suitable ones should be carefully selected for each purpose. We adopted copper-constantan thermocouple for temperature measurement in the experiment. Thermocouple outputs voltage proportional to temperature difference between reference and the measuring junctions. We also used an audio-microphone as a sound sensor, which outputs voltage according to oscillation of atmosphere.

Table 1. Specification of ADC-11[5]

Resolution	10 bits.
Input channels	11 channels.
Input voltage range	0 - 2.5V.
Typical sample rate (on 100MHz Pentium)	15k Sample / s.
Linearity	±1 LSB at 25℃.
Accuracy	±1%.
Input overvoltage protection	±30V.
Input impedance	>1MΩ.
Digital output voltage	Typically 3 - 5 volts.
Digital output impedance	Approx. 1 - 3k ohms depending on PC.
Input connector	25 way female D-type.
Output connector	25 way male D-type. (connect to PC printer port)

Table 2. Input pin connections of ADC-11[5]

Input pin number	Function
1	Digital output
2	Signal Ground
3 - 13	Channel 1 to 11
14	Auxiliary digital output
15 - 25	Unused

Table 3. List of electrical parts used for the amplifier.

Electrical parts		Quantity
Circuit board		1
Fixed resistor	1 kΩ	1
	4.7 kΩ	3
	510 kΩ	1
	5.1 MΩ	1
	5.6 MΩ	2
Variable resistor	10 kΩ	1
Potentiometers	10 kΩ (multiple turns)	2
Multilayered ceramics capacitor 0.1μF		2
Op-amp IC LM358 (NS)[11]		1
2.5 V reference IC LM336Z-2.5 (NS)[12]		1
Johnson Terminal (red and black)		2 of each
DC jack		1
Aluminum chassis		1

AD Converter

As the natural properties are analogue quantities whereas PCs are accessible only to digital ones, any data should be converted from analogue to digital values. The AD converter is a device for the purpose that converts from analogue to digital voltage. For present system, we used

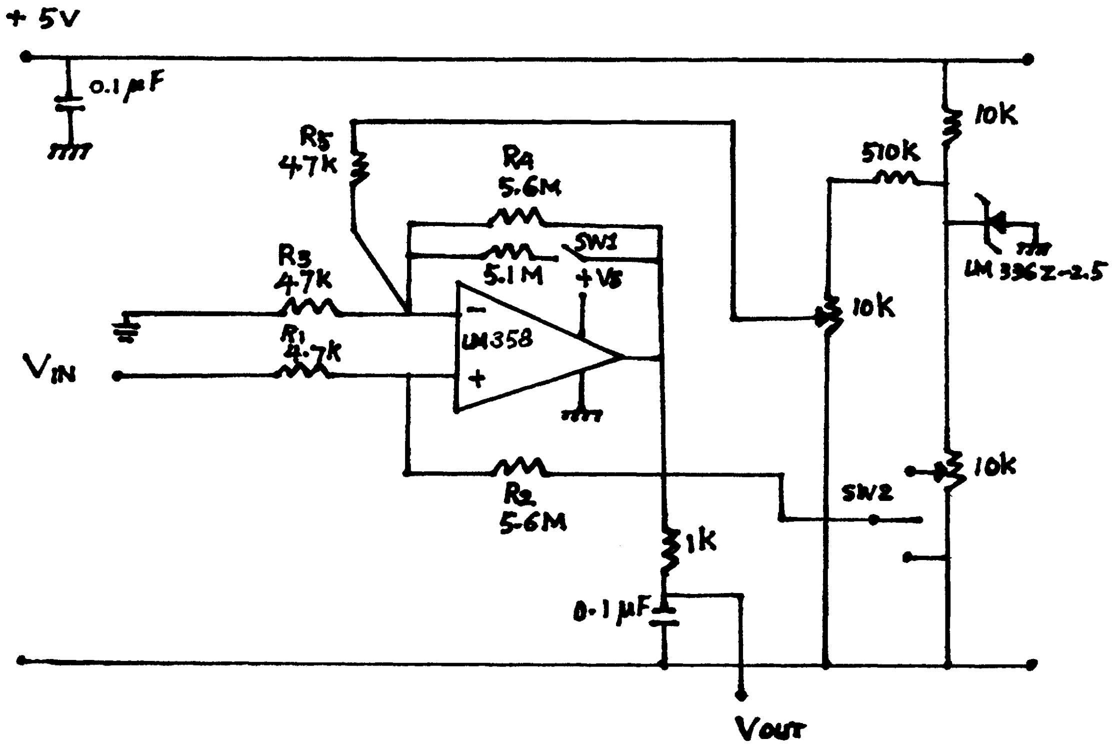

Fig. 2. Circuit diagram of voltage amplifier designed for the use with ADC-11.

ADC-11 (Pico Technology Ltd.) as an AD converter which costs ¥8,500. The ADC-11 is a medium speed converter with 11 input channels and 1 digital output. Tables 1 and 2 summarize its specifications and pin connections, respectively.

Controlling software provided with ADC-11 includes PicoScope and PicoLog programs run on Windows operating system. High speed data acquisition at time interval of about 1 ms is possible with PicoScope, though the data acquisition is limited up to 500 samples at one series. It is applicable to signal processing below 1 kHz. On the other hand, PicoLog is used as a long term data logger at interval above 1 s.

Signal Modifier

Electrical signal output from the sensor may be in electrical voltage, current or resistance. On the other hand, AD converter accepts only an voltage within a well-defined range. The signal modifier is a device for transducing the sensor signal into voltage and amplifying or attenuating to the input range of AD converter. Since sensor outputs are voltage of mV range in the present system, we have to use an amplifier for signal modifier.

Interface

Many kinds of interfaces are used for data transfer from and/or into computer, such as RS-232C, parallel, USB and GP-IB interfaces depending on the peripheral device connected. The GP-IB (or HP-IB) interface is advantageous

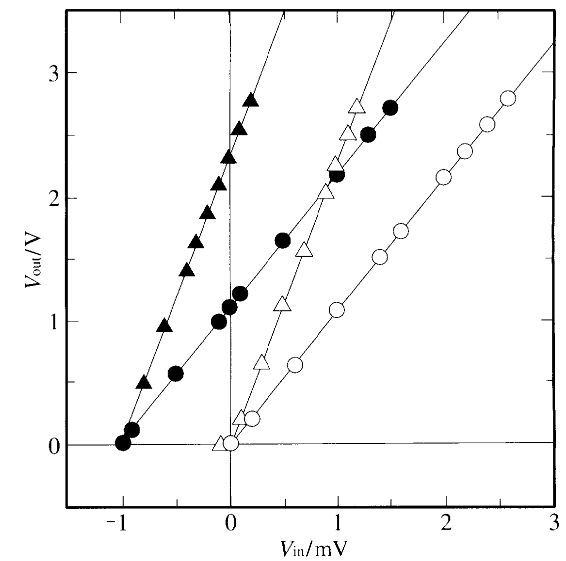

Fig. 3. Input-output characteristic of voltage amplifier. Open and closed marks indicate bias voltage (V_{ref}) off and on, respectively. Triangles and circles indicate high and low gains, respectively.

Table 4. Best fit parameters for input-output characteristics of amplifier. Gain shown in the last column is obtained by $10^3/A_1$.

Mode		A_0	A_1	Gain
Gain	V_{ref}			
high	off	0.0085	0.4379	2283
high	on	− 1.0144	0.4365	2291
low	off	0.0075	0.9246	1082
low	on	− 1.0138	0.9239	1082

Fig. 4. Experimental setup for recording sound wave.

in its speed and generality in use of data acquisition. However, the GP-IB interface card is usually too expensive to apply for school science, and the controlling software has to be made by the end user. On the other hand, the former three are usually ready to use in most of computers as purchased. Thus the devices using these interfaces are advantageous in reducing the cost. The ADC-11 is connected to parallel port on PC with which makes fast communication possible.

Ⅲ. Building of an Amplifier

Construction

We have designed a voltage amplifier suitable for the present experiments. The specification required for the amplifier is as follows.[6, 7]

(1) The gain required is about 500 to 1000 times, because the signal from sensors is mV range whereas the input range of ADC-11 is 2.5 V.

(2) The bias voltage can be applied to output voltage for about 1 − 1.5 V, since the input range of ADC-11 is 0 − 2.5 V. Biased output allows us to put negative voltage for the input of ADC-11.[8]

Circuit diagram of the amplifier we designed was shown in Fig. 2, and the list of electrical parts used for the circuit were compiled in Table 3. For power supply of the circuit, a disused AC adaptor for a cellular phone was adopted. Since power consumed within the circuit is small, any kinds of AC adaptors which outputs ～ 5 V in DC are expected to be available. The total cost we spent for the amplifier was about ¥3,000.

Characterization

The circuit can be used in one of 4 different modes depending on gain and bias voltage selecting with two switches SW1 and SW2 (see Fig. 2). The switch SW1 selects

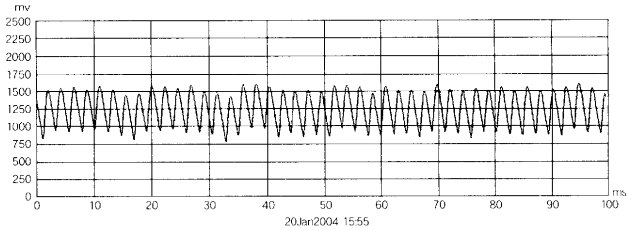

Fig. 5. Sound wave from tuning fork

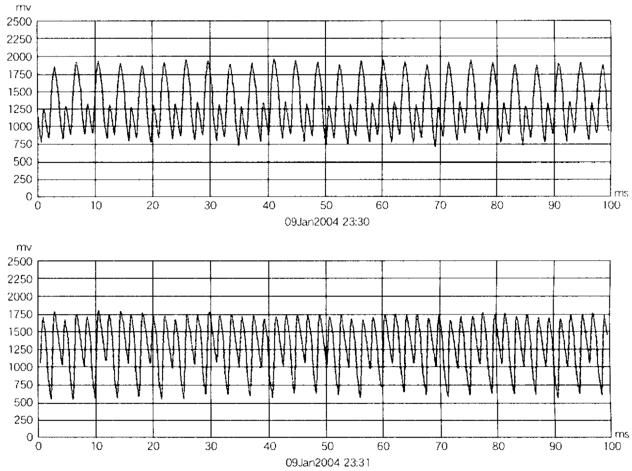

Fig. 6. Sound wave from violin for key C.
Upper: bowing up; lower: bowing down.

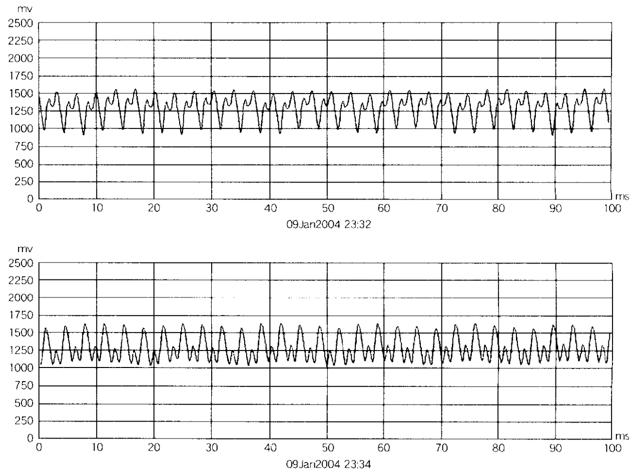

Fig. 7. Sound wave from violin for key D.
Upper: bowing up; lower: bowing down.

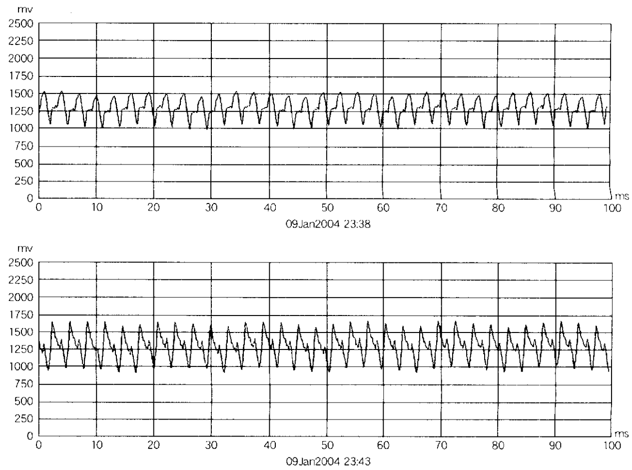

Fig. 8. Sound wave from violin for key E.
Upper: bowing up; lower: bowing down

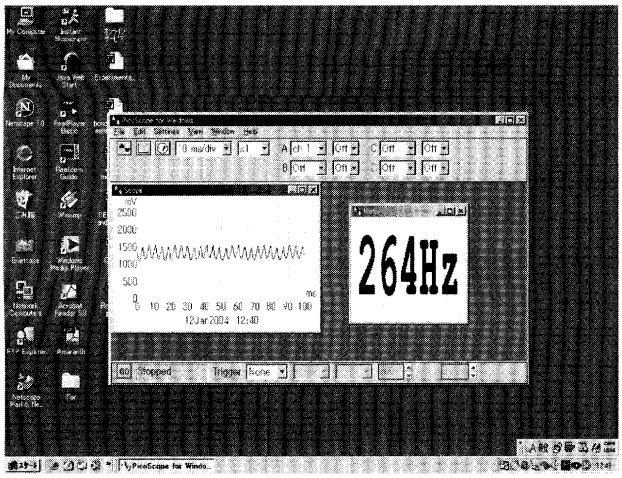

Fig. 9. A screen-shot of PicoScope measuring piano sound wave of key C_4

Fig. 10. Experimental setup for measurement of heat of solution

high or low gain and SW2 bias on or off. To check characteristics of the circuit, output voltage was measured by digital multimeter (Keithley Inc.; DMM-2000) against input voltage applied from the DC voltage standard (Yokogawa Electric Co.; Type 2553).

In Fig. 3 the input-output characteristics determined is shown for each mode. The linear function has been obtained by least squares method as

$$\left(\frac{V_{in}}{\mathrm{mV}}\right) = A_0 + A_1\left(\frac{V_{out}}{\mathrm{V}}\right) \qquad (1)$$

where A_0 and A_1 are fitting parameters. Optimized values for A_0 and A_1 are compiled in Table 4.

Ⅳ. Application to School Science Experiments

Observation of Sound Wave

Overview

Sound is the wave of the molecular or atomic displacement traveling through a medium. Sound wave traveling in the air is longitudinal branch only with which high and low density part of atmosphere propagate correlatively. It is possible to transduce sound wave to electrical wave with microphone. In the following experiment the students can observe the wave of sounds invisible in daily life.

Visualizing the sound wave using PC is already included in the physics textbook for high school using an expensive commercially available acquisition system. It is checked if the present system is enough capable of detecting sound as oscillating phenomenon.

Experimental

Figure 4 shows the experimental setup for detecting sound wave signal. A commercially available microphone was used for the sensor. The amplifier was used in high-gain and V_{ref}-on mode. To reduce the noise, the lead wire of microphone was covered with aluminum foil.

The obtained signal was recorded with PicoScope on notebook PC (NEC VersaProNX; CPU: Intel Celeron 266 MHz, memory: 96 MB, OS: Microsoft Windows98 2nd Edition). The sampling interval achieving 1 ms with PicoScope helps us to use PC as an oscilloscope.

As sound sources, we used tuning fork, the violin and the piano. Using tuning fork and violin, the sound wave was detected with PC, and the frequency was also evaluated for the piano.

Results and Discussion

Tuning fork

The tuning fork is known as sound source that shows clear monochromic sound wave. This means that sound wave from tuning fork looks like a sine wave. Figure 5 shows the sound wave observed for a tuning fork. As is expected, a sine wave is clearly recorded. This indicates that the system has enough ability to use as sound wave detector. However, unevenness of the sound wave at long wave length is due to the noise from the wire of microphone not completely removed by shielding with aluminum foil.

Violin

In Fig. 6 through 8 sound waves from the violin were shown at different keys of C, D and E. It is observed that not only difference in frequency but also the shape of the wave. This means that the oscillation includes many frequency components with different distribution. Since the frequency distribution is not analyzed yet, the difference in frequency distribution is not clear. However, such analysis is expected in the future.

It is also observed that sound wave obtained by bowing up and down is clearly different. In all keys, they look just like mirror images except for the amplitude. It is supposed that this is because of difference in the relative amplitudes and phases of multiple frequency components. It is supposed that such difference results from the surface structure of bow made of tails of horse.

Piano

For taking sound wave from the piano, PicoScope was used not only to display wave signal but also frequency value. Measurements were carried out for different keys of C_4, E_4, G_4, $B_4{}^b$ and C_5. Figure 9 is an example of screen shots measuring sound wave from the piano. It is observed that the sound wave from piano resembles single frequency oscillation implying small contribution from multiple frequency. As seen in Fig. 9, the frequency value is displayed numerically in real time. The observed frequency value 264 Hz for the key C_4 agreed with the ideal value[9], whereas some others did not. It is considered that the deviation from ideal value results from bad tuning of the piano.

Measurement of Heat of Solution

Overview

Measurement of temperature is common technique in various aspects of school science. However, temperature measurements often take so long to finish the experiments. It is useful to introduce PC data acquisition system to such boring experiments. This not only frees us from painful measurements but gives us more precise and high resolution measurement.

We applied our system for the measuring the heat of solution of two kinds of electrolyte crystals into water. Heat of solution is detected as temperature change on dissolving solute into solvent. Nasu *et al.*[10] measured heat of solution for some salts using commercial acquisition system. We have measured endothermic and exothermic processes observed on dissolving ammonium nitrate (NH_4NO_3) and sodium hydroxide (NaOH), respectively. Both substances are typical solids with large thermal effect on dissolution among chemicals familiar at school. If carried out the present experiments, students can notice the little change of heat of dissolution and deepen their scientific inquiry. Hereafter we sometimes use the term enthalpy of solution which is equivalent to heat of solution under isobaric condition from the viewpoint of thermodynamics.

Experimental

For temperature measurement Copper-Constantan thermocouple (Cu-Con TC; Type T) is used for a temperature sensor. It is a device detecting temperature difference between the sensing and reference junctions as electromotive force (EMF). The reference junction generates its own temperature dependent EMF which must be taken into account when interpreting the total measured thermocouple voltage.[14,15] As cold reference junction, we used ice point as placing junction in stored ice. This point makes it possible to maintain at low cost and long term experiment is possible. As data-acquisition software, PicoLog was used which is available for long term experiment. However, the interval of reading is about 1 s at fastest. In Fig. 10 the experimental setup is shown.

Polystyrene foam cup was used for experimental chamber. Distilled water of 100 ml was put into the cup and stirred well with magnetic stirrer. The thermocouple measuring junction was inserted to the water covering with thin glassy cap. The top of the cup was covered with a cap made of polystyrene foam to minimize heat exchange with the environment.

Mass of the solute was measured with electrical balance. In several minutes after the temperature measurement started, solute was put into the cup and keep on measuring temperature. Since the temperature rise or drop depending on materials, the temperature was kept on monitored for 5 to 15 minute depending on the experiments until the temperature drift looks disappeared. As the averaged temperatures before and after the temperature drift was obtained as initial and final temperatures, respectively.

For chemical reagents commercially available ammonium nitrate (NH_4NO_3; Special grade reagent from Wako Pure Chemicals Industry Ltd.) and sodium hydroxide (NaOH; Special grade reagent from Sigma-Aldrich Japan K. K.) were used without further purification. Experiments were repeated for several times with different amount of samples.

Results and Discussion

Evaluation of Temperature from EMF of TC

To get temperature value from the reading of AD converter, we need two steps of calculation. The first is to obtain input from output voltage of the amplifier carried out with eq. (1), and the second is to convert the EMF of TC into temperature.

Using the table of standard EMF values for Cu-Con TC provided from Japan Industrial Standards (JIS), the relation between temperature and EMF of Cu-Con TC was fitted with the second order power polynomial;

$$\left[\frac{\theta}{℃}\right] = a_0 + a_1\left[\frac{E_{TC}}{mV}\right] + a_2\left[\frac{E_{TC}}{mV}\right]^2, \qquad (2)$$

with constants a_0 through a_2. In eq. (2), θ and E_{TC} are the temperature and the EMF of TC against ice point, respectively. By the least squares method using data of temperature range between −100 to 100 ℃, we determined parameters as $a_0 = -2.55 \times 10^{-17}$, $a_1 = 26.496$ and $a_2 = -0.78796$. Combining with Eqs. (1) and (2), and setting $V_{in} = E_{TC}$, we obtain the following relation.

$$\left[\frac{\theta}{℃}\right] = \left\{ a_0 + a_1A_0 + a_2A_0^2 \right\} + \left\{ a_1A_1 + 2a_2A_0A_1 \right\}\left[\frac{V_{out}}{V}\right] + a_2A_1^2\left[\frac{V_{out}}{V}\right]^2 \qquad (3)$$

Since used mode of amplifier was of low-gain and V_{ref}-off, parameters of $A_0 = 0.0075$ and $A_1 = 0.9246$ can be used.

$$\left[\frac{\theta}{℃}\right] = 0.1996 + 24.49\left[\frac{V_{out}}{V}\right] - 0.6736\left[\frac{V_{out}}{V}\right]^2 \qquad (4)$$

Initial and final temperature values were determined via eq. (4) from averaged readings. As the resolution of voltage is about 2.5 mV which corresponds to the temperature resolution about 0.05 ℃ at the present configuration. It is also expected to be more precise by averaging over long time.

Heat of solution

Figure 11 shows typical temperature drift curves on dissolution of ammonium nitrate (NH_4NO_3) and sodium hydroxide (NaOH). The temperature diminished for NH_4NO_3 indicating endothermic process, whereas increased for NaOH indicating exothermic one. In these runs 0.04 mol of NH_4NO_3 or NaOH were used where temperature changes of −1.8 K for NH_4NO_3 and 3.7 K for NaOH were involved. The time taken for completing the dissolution is far longer for NaOH than for NH_4NO_3. This is because NH_4NO_3 is supplied with in powder whereas NaOH in granular form.

In Fig. 12 the enthalpy of solution ΔH obtained as

$$\Delta H = -C\,(m_{water} + m_{solute})(T_f - T_i) \qquad (5)$$

are plotted against the amount of solute n. In eq. (5), C indicates the specific heat capacit of water, m_{water} and m_{solute} masses of water and solutes, ant T_i and T_f temperatures before

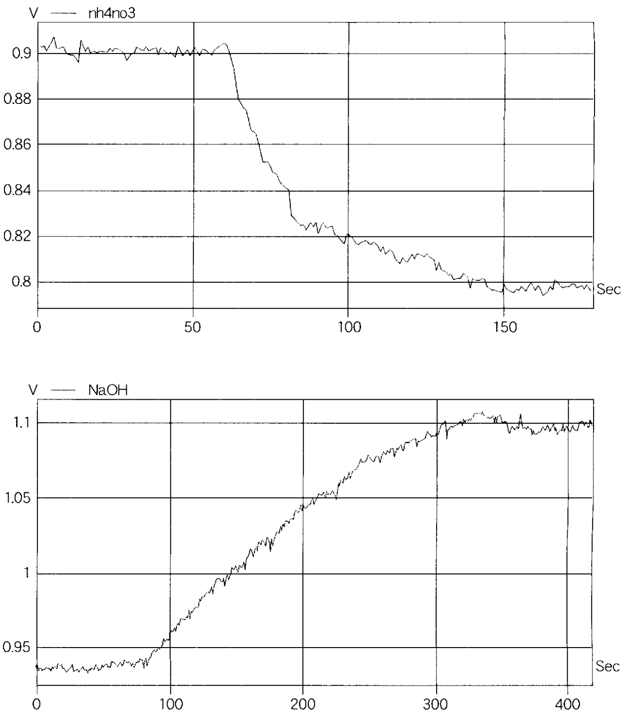

Fig. 11. Time dependence of EMF of TC caused by dissolution into water of ammonium nitrate (upper) and sodium hydroxide (lower).

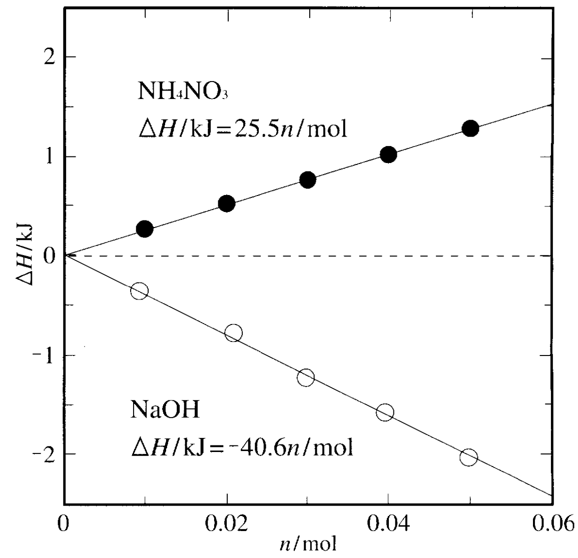

Fig. 12. Observed enthalpy of solution plotted against the amount of solute. Solid lines and its functions are obtained by least squares method.

and after the dissolution, respectively. For both solutes the data show linear relationship as expected. The degree of data-scattering for NaOH seems to be close essentially to that of NH_4NO_3. This implies the long time measurement for NaOH is not responsible for the experimental error.

Slopes of lines, indicating the molar enthalpies of solution, obtained by least squares method are 25.5 kJ mol^{-1} and −40.6 kJ mol^{-1} for NH_4NO_3 and NaOH, respectively. For NH_4NO_3 the obtained enthalpy of solution was only 0.8% smaller than the literature value 25.7 kJ mol^{-1}.[11] Since this deviation is smaller than the error expected from the temperature resolution (~ 2.5% at the best), the present method of measurement and analyses should be satisfiable. For NaOH, on the other hand, the obtained enthalpy of solution is about 10% smaller in absolute value than the literature value of -44.51 kJ mol^{-1}.[11] It should be noted that NaOH normally contaminated by moisture and CO_2 because of its hygroscopic and basic properties. The resultant substances such as Na_2CO_3 are expected to show smaller enthalpy of solution even if it is exothermic, although we could not reach any literatures presenting the enthalpy of solution for Na_2CO_3.

V. Conclusion

Introducing computer for the help of science education, it seems most important to consider if it is advantageous for science education not for computer education. The PC-based experimental measurement seems to be one of the most suitable application of PC in school science. We have presented that the system is cheap and precise enough to introduce into any kinds of school science. Also, the generality in application of this system gives the enormous possibility for using any kinds of experiments in school science. The next challenge is to develop more concrete teaching guides using the present system.

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