Stray Cats – Lively and Exciting Physics Demonstrations – Group 4 - Electrostatic Pendulum, its Extension and Advancing Science Workshop -

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Abstract

As the seventh presentation of Stray Cats demonstrations, experiments on electrostatic pendulum and its extensions are shown at first. It is a good exercise for the students to think about the reasons why the pendulum continues to swing. Finally, our activity of Advancing Science Workshop (ASW) at Nagoya City Science Museum is introduced. The ASW aims at encouraging high school students to learn and enjoy natural science through the design, construction, and operation of their own experimental devices.

1 Introduction

It is of primary importance to encourage high school students to study natural science, because the number of students who major science and technology tends to decrease year by year. This tendency is our great concern, because the future of this country definitely depends on how these students can contribute to the development of science and technology of the nation.

It will be difficult for the students to understand abstract concepts that appear in physics, electricity and magnetism. The demonstration experiment is a powerful tool when introduced in the lecture to assist students for comprehensive study of electricity and magnetism. Simple experimental devices have been designed and constructed for lecture demonstrations. An electrostatic pendulum is adopted for understanding physical concept of electrostatic force and the difference between gravitational and electrostatic forces.

The idea of "Advancing Science Workshop (ASW)" was initiated from the discussion among the teachers who attended the event "Science Festival for Youngsters" regularly organized by Nagoya City Science Museum (NCSM), that only one day for lecture and experiment is not enough, but a continuing effort is absolutely necessary for further training of high school students who are interested in science. Accordingly, approximately 10 teachers from senior high school and college gathered under Dr. Y. Yamada at NCSM to discuss how we could realize this idea, and established an *ad hoc* organizing committee for ASW in the fall of 2002, aiming at starting its activity in 2003.

The objective of ASW is to let youngsters explode their interests in science by enjoying the science through their own experience, and contribute to productive science education in Japan.

2 Electrostatic pendulum

The pendulum has widely been utilized in the physics experiments. The pendulum combined with electrostatic force becomes not only an interesting scientific toy, but also a good material to understand the physics. The pendulum suspended in the middle of two vertically placed electrodes to which a DC high voltage is applied will continue to swing. Students will wonder why it swings continuously. Without any voltage applied, the pendulum will swing as known with a period determined by the length of the pendulum l, the amplitude becomes smaller and smaller, and finally stops swinging. When electric field is present between two electrodes, the pendulum assumed to leave positive electrode, will be charged up positively and accelerated toward the negative electrode with electrostatic force determined by the amount of charge q, and the intensity of electric field E. The pendulum will release the charge when it contacts with the surface of the negative electrode, and be charged up negatively, attracted toward the positive electrode, giving a continuous swinging. Because the electrostatic force is independent on the mass, the period of the swing will become surprisingly shorter, when the pendulum is replaced with a much lighter one.

The gravitational and electrostatic forces acting on the pendulum are shown schematically in Figure 1.

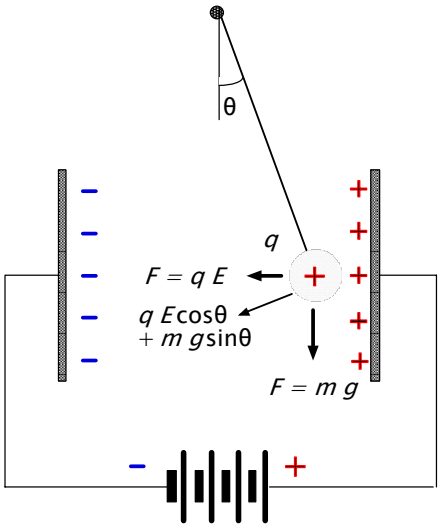

Figure 1. The gravitational and electrostatic forces acting on an electrostatic pendulum

The equation of motion for the pendulum is expressed as follows, where θ is the deflection angle, m the mass of the pendulum, and g the gravitational acceleration.

$$l\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} = -g\sin\theta - \frac{qE}{m}\cos\theta \qquad (1)$$

Under the condition that the deflection angle is small,

$$l\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} = -g(\theta + \frac{qE}{mg}) \ , \ \text{for } \theta << 1 \qquad (2)$$

Introducing a new variable $\phi = \theta + (qE/mg)$, the following expression will be obtained, giving a solution of a simple harmonic oscillation.

$$l\frac{\mathrm{d}^2\phi}{\mathrm{d}t^2} = -g\phi, \quad \text{for } E \approx \text{constant}. \qquad (3)$$

It should be noticed that the range of θ is between θ_0 and $-\theta_0$, and that the polarity of the charge will be reversed at θ_0 or $-\theta_0$. The fact that the solution of above equation is a simple harmonic oscillation for the new variable means the motion of the pendulum is expressed as a simple harmonic oscillation with a biased deflection angle determined by qE / mg. This is equivalent to a mechanical shift of the pivot against the direction of pendulum motion.

It is also necessary to take the initial velocity of the pendulum when it leaves the electrode into account, because it strongly depends on the property of the electrode surface and the velocity when the pendulum hits the electrode.

This electrostatic pendulum can be used for detecting the polarity of charge generated with friction.

3 Electrostatic torsion pendulum

The pendulum replaced with a short wire acts as an electrostatic torsion pendulum. A plan of the torsion pendulum is shown schematically in Figure 2.

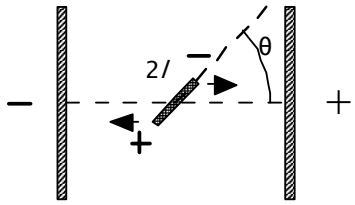

Figure 2. The electrostatic force acting on an electrostatic torsion pendulum

The electrostatic force acting on the pendulum is expressed as follows, with a rotation angle θ, moment of inertia I, restoring force of the string k, length of the pendulum l, and a constant A:

$$I\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} = -k\theta - 2AE^2 l\sin\theta\cos\theta$$

Again under the condition that $\theta << 1$,

$$I\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} = -(k + 2AE^2 l)\ \theta$$

This also gives a solution of simple harmonic oscillation as follows:

$$\theta = \theta_0\cos\omega\, t, \qquad \omega = \sqrt{\frac{k + 2AE^2 l}{I}}$$

The frequency of this simple harmonic oscillation is proportional to the intensity of the electric field applied, if the natural frequency determined by the restring force of the string is low enough, that is, $k<<1$.

In figure 3 is shown an experimentally obtained swing frequency of the pendulum as a function of electric field intensity applied.

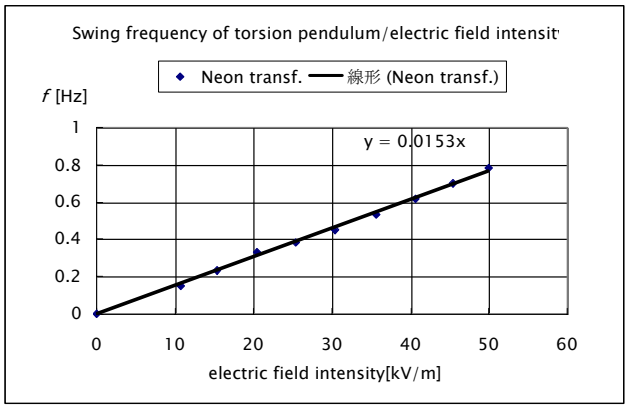

Figure 3. The swing frequency of torsion pendulum as a function of electric field intensity

4 Activity of Advancing Science Workshop

4.1 Objectives

Following the discussion among science teachers to promote the science education of young students, approximately 10 teachers from senior high schools and colleges gathered under Mr. YAMADA, Y, a curator at NCSM to discuss how we could realize this idea, and established an informal organizing committee for ASW in the fall of 2002, aiming at starting its activity in 2003.

The objective of ASW is to encourage students to learn and enjoy science with the observation of interesting demonstration experiments, construction of their own experimental devices, and mutual discussions.

In 2003, the following four courses were held, six consecutive Saturdays as a rule: "Challenge to construct my motor", "The world of electron exchange processes", "Challenge to velocity determination of sound and light", and "Challenge to the seven wonders of light".

4.2 Record of the workshop

(1) Challenge to Construct My Motor
- Lecturer: KAWADA Hideo
- Contents:
  1. Principle of DC motor, construction of a kick motor.
  2. Principle of AC motor, construction of an induction motor.
  3. Construction of an electrostatic motor.
  4. Design of an original motor based on student's own idea.
  5. Construction of an innovative motor.
  6. Presentation of student's own research, summary, questionnaire, and information exchange.
- Review and conclusion:
  1. Although the classes have been finished as planned, more balanced distribution of time should be considered.
  2. All of the students have succeeded to construct their own original motors.
  3. Experiments presented by the students with their own idea, and demonstration experiments by the instructors received a favorable notice from the students.
- Prof. RYU Tai at Sophia Univ. kindly gave us a special lecture on "New physics education in England."

(2) The World of Electron Exchange Processes
- Lecturer: HAYASHI Masayuki
- Contents:
  1. Carry out the following seven basic experiments one by one, observe the reactions carefully, think about the meaning of obtained results, and submit the reports:
     a) Reaction between metal and aqueous solution
     b) Reaction related to non-metal
     c) Daniel cell
     d) Kitchen cell
     e) Electrolysis of lead chloride
     f) Electrolysis of aqueous solution of sodium sulfate
     g) Nickel plating
  2. Study the theory of electron exchange reaction and acquire the knowledge from the viewpoint that how the modern chemistry explains the meaning of obtained experimental results and answer the related questions arisen. In the course, demonstrate an experiment concerning the fuel battery and electrolysis by the use of ion-exchange membrane.
  3. Find out own research subject from the standpoints that "I want to try this", "Is it correct to understand in this way?" Verify these questions with experiments.
  4. Presentation of research and exchange of opinions. Discuss the topics what students have learnt at ASW, and how science should be for human being.
- Research subject:
  1. Let's construct a battery with drinks.
  2. Let's construct a battery in which non-metal catches electron at an anode.
- References: Details of the contents and the reports will be found in the following home page: http://www.water.sannet.ne.jp/masasuma/masa/ncompmenu.htm

(3) Challenge to Velocity Determination of Sound and Light
- Lecturer: HAYASHI Hirotaka
- Contents:
  1. Measurements of resistance: pure metal and alloy. Understand the temperature dependence of resistance through experiments.
  2. Measurements of time-varying voltage with an oscilloscope.

3. Measurements of sound velocity; in the air, in carbon dioxide, in helium, and in the air at low pressure. Understand the difference.
4. Measurements of sound velocity in the water, aluminum, and granite.
5. Trial of light velocity measurement by the use of a laser light chopped with high speed rotating mirror and reflected from distant fixed mirrors.

- Prof. NIWA Kimio at Elementary Particle Physics, Nagoya University kindly gave us a special lecture and conducted a guided tour of the experiments.
- Review and conclusion:
  1. The number of participants was as few as only two, partly because the course was held during summer vacation. Nevertheless, the students presented dense research results with their own ideas.
  2. Some inconvenience for the instructors to join because the later part of the course was held at Nagoya University.

(4) Challenge to Reveal the Seven Wonders of Light
- Lecturer: FUJITA Junji
- Contents:
  1. Measurements of the focal length of lenses. Construction of a light sensor by the use of phototransistor, a compact spectrometer with used CD. Demonstration experiments on spectroscopy.
  2. Construction of an experimental device for light reflection and refraction. Observation of spectral lines from various discharge lamps. Demonstration of light refraction and rotation of polarization through a sugar solution with density gradient.
  3. Demonstration of three basic colors with a computer. Construction of Levenhook's microscope and observation of a plant cell.
  4. Explanation of light polarization and liquid crystal display. Experiment of stereoscopic slide projection by the use of polarization films. Lecture demonstration of light interference.
  5. Presentation of student's own research, summary, questionnaire, and information exchange.
- Guided tours of National Institute for Fusion Science (NIFS) at Toki City was held on the third day of the course. Brief explanation was given in a previous week with a promotion video of NIFS.
- Director HIGUCHI Keiji (NCSM) kindly gave us a special lecture on "Why the moon looks large."
- Review and conclusion:
  1. Not enough time was given to the construction of experimental devices, so that the course was somewhat biased to the demonstrations and lectures.
  2. The students showed their strong interests in the observations of a cell with self-constructed microscope, spectral lines from discharge lamps, black flares, and the light refraction through a sugar solution.
  3. The visit to NIFS received a favorable notice from the students.

4.3 Concluding remarks

We have carried out the course with try and error base, because it was the first year for ASW. We are surprised how strong are the students' interests in science and their positive attitude toward it, and encouraged by this rich imagination beyond our expectations. At the same time, we are noticed several problems to be reviewed as follows:

1. The arrangement of times for the class; 6 days for one theme, 3 hours per day, was just appropriate.
2. Students have difficulty to attend the class in summer vacation period, because of events at their school, club activities, camps for training, family tours, and so on.
3. A similar schedule as this year one course in the first term, and another in the second, seems to be adequate, taking the school events into account.
4. We shouldn't restrict the participants to senior high school students, but open to the public including university and college students, as we did in the fourth course.
5. A cooperating system should be established among instructors and lecturers, not totally dependant on the lecturer.
6. We should make efforts to include *impromptu* experiments by instructors, presentations of students on their original experiments and others in balance, for all members to join actively.
7. Call for instructors widely besides teachers.

We should pursue effective actions for public relations.

5 Conclusions

An electrostatic pendulum and its extension are shown to be an instructive tool for students to understand electromagnetism and related physics.

The activity of Advancing Science Workshop at Nagoya City Science Museum is also introduced.