Articles

An Experiment with Cellular Phones in General Physics Education

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Recently cellular phones are used worldwide as convenient communication tools. In spite of that, very few people understand the underlying physics. Of course, underlying mechanisms of other electrical equipments such as TV, radio, and so on, are also not fully understood by many people. However, cellular phones are used anytime and anywhere, with or without partners, but can they be used safely without the knowledge about their mechanisms? In fact, their usage may occasionally threaten other people's life if used in improper ways, such as disrupting pacemakers of the heart-disease patients. As a result, the society may need to restrict their usage in order to protect people's safety. Such restrictions might be imposed even if there is lack of correct knowledge about them in order to prevent that some people may use them ignoring the safety of the other people. Therefore, as cellular phones spread all over the world, it is important for us both to understand their mechanisms scientifically and to learn their proper usage. Accordingly, we believe that it is important to give the students the opportunity to understand their mechanisms. In this paper, we would like report our trial of designing the cellular-phone experiments in general physics education for the science and engineering students.

1. INTRODUCTION

In our science/engineering courses, about 1000 students learn experiment courses as a part of general physics education. In order to survey their opinions about the physics experiment and their study, the questionnaire has been conducted for all students over the last few years.

According to the results, before entering an university, 60% of students have not experienced a physics experiment. And most students who experienced a physics experiment cannot remember the theme of the experiment. Because of such situations, their evaluations for almost all the experimental themes are more or less "not bad, but not good either." However, there is only one exceptional theme, which more than 80% students have given high marks. This experiment theme is a low temperature experiment which uses a liquid nitrogen. We considered the cause of such high mark as follows, (1) a phenomenon which changes dramatically can be directly observed, (2) it is easy to write the lab report, (3) there is almost no difficult calculation, and (4) the experimental time is comparatively short. Here, when we consider other experiments, only reason (1) does not exist in other experiments. So, the dramatic phenomenon seems to be the most important factor of their evaluations.

Well, are many students interested in a physics phenomenon which can be seen everyday? Although they always have used it very conveniently, they do not understand the phenomenon which happens in it. We want to adopt such things in our
new experiment. Of course, we do not choose the experiment theme only because the student may be interested. During the course of designing our physics experiments, an important physics theme is still the guiding principle. Nevertheless, we thought that it would be useful to introduce tools, which are used in daily life, into our experiments. As a suitable candidate, we identified cellular phones (wireless phone). Nowadays, almost all young people use cellular phones regardless of the time and the place. But they do not understand at all how cellular phones operate. Moreover, the users often cause trouble with people nearby, and cellular phones could even be perceived as environmental problems. For such reasons, we decided to adopt cellular phones as our experimental theme. However, until now there are almost no experiment educations using cellular phones, and freshmen have difficulties to understand an electromagnetic wave. Of course, we must be careful that the electromagnetic wave of cellular phones is used lawfully. For these reasons, until now we continue to refine the contents of this experiment.

2. COMPOSITION OF THE EXPERIMENT
In deciding the outline of the experimental contents, we have taken into consideration the following factors.

(1) It may be difficult for freshmen to understand an electromagnetic wave quantitatively.
(2) It is too difficult to understand the device circuit of cellular phones which is high-tech in essence.
(3) Even for freshmen, qualitative understanding of an electromagnetic wave is possible.
(4) The mutual interference among many prepared experimental sets is made as small as possible.
(5) Since many experimental sets are prepared (six sets in our course), we want to make as cheaply as possible.

The details of the experiment were decided so that the criterion described above is fulfilled.

(1) Experiment of cellular phones.
(2) Experiment of the modulation using a radio frequency band (7 MHz).
(3) Experiment using the antenna of UHF-TV (450 MHz).

The whole experiment consists of the above three parts. In the experiment I, the electromagnetic wave of cellular phones is measured. In the experiment II, students learn how information will be sent by the electromagnetic wave. Before the experiment, most students do not know that the electromagnetic wave is modulated by information and is transmitted and received. Therefore, we do not think that the experiment II would be useless as a major part of the experiment. In experiment III, students intuitively find the character of the electromagnetic wave of the wavelength band of cellular phones using both transmitter and the receiver which consist of UHF television antennas. In our experimental course, six groups need to carry out the experiment simultaneously in one room. If six groups perform the experiment of the same wavelength, it will interfere each other and the experiment will become impossible. Therefore we have to prepare the experiment for at least three different wavelengths.

3. EXPERIMENT
3.1. Experiment of Cellular Phones
For this experiment, students use their own handheld phones. Hereafter, hand-held equipment which each one uses is named "hand-held phone." During the experiment, the communication partners' cellular phones are placed outside the room. Otherwise, they can disturb the hand-held phones under the measurement when they transmit electric waves for non-intended communications. In the actual experiment, since the students communicate with each other using two hand-held phones, one of two phones is placed on the pathway. Two desks for the cellular phones are placed in the room and the aluminum boards shield them electrically on each desk. And what should be handled with care is that we cannot take out the information from cellular phones freely.

3.1.1. An Electromagnetic Wave Which Has Come from the Base Station Antenna of the Cellular
Reflection and skin effect of the electromagnetic wave are confirmed using a metal box and a metal basket, as shown in Fig. 1, 2, and 3.

Fig. 1: Hand-held phone in the cookie box.  Fig. 2: Basket for the ultrasonic washing machine.  Fig. 3: Powder sieve with lid.
Under the circumstances, the students count the number of the antenna sign at the display of the hand-held phone, which indicates the intensity of incoming waves. When the electromagnetic wave does not reach the hand-held phone in the box etc., nothing appears on display. The box is covered with a lid. After about one minute, we take away the lid and quickly observe the antenna sign at the display of the hand-held phone.

When the base station antenna of the cellular phones is near, the electromagnetic wave of an about 1 GHz band passes through the iron board of the thickness like a cookie box. In such a case, after the box is put into another larger box, we observe similar antenna sign as we open the inner box. Moreover, under this condition the hand-held phone in the box is called from the outside.

Next the hand-held phone is put into the steel basket whose lattice spacing differs as shown in Fig. 2 and 3. By observing the antenna sign on the display, the intensity change of the electromagnetic wave from the base station antenna is measured. Diffraction of an electromagnetic wave can be observed in this experiment. One of metal baskets used is the one for the ultrasonic washing machine and another is a powder sieve which has 1 mm mesh (with a lid). In the case of the basket, the display of the hand-held phone can be seen directly.

3.1.2. Electromagnetic Wave of a Hand-held Phone
Following the textbook, one measures the electromagnetic wave of the hand-held phone of the student. And shield boards are used in order to reduce the influence from another hand-held phone experiment.

The wave detector of 0.8-1.6 GHz band with the received ammeter is prepared. As shown in Fig. 4, at first the hand-held phone is placed parallel to the antenna of this wave detector, detached about 1 cm. Next the power supply of the hand-held phone is turned off, and turned on after about thirty seconds. Then, the students notice that detected response differs depending upon cellular and models of the hand-held phone.

As a result, they recognize that each cellular company is employing different ways of communication and point detection.

3.1.3. Polarization of the Electromagnetic Wave of a Hand-held Phone
As shown in Fig. 5, the hand-held phone is placed parallel to the antenna of this wave detector, detached about 50 cm. The distance between the detector and the hand-held phone is adjusted so that about 50 micro-amperes may flow. Next, while observing the detector current, the hand-held phone is rotated slowly around the axis which connects both equipments, as shown in Fig. 6. Then, when antennas are perpendicular to each other, the detector current becomes the minimum. This phenomenon shows that the electromagnetic wave of the hand-held phone has linear polarization. Antenna of the hand-held phone is separated from the detector 50 cm and is put parallel to that of the detector. Then the metal ladder is placed between them. It is shown in Fig. 7. When both the antenna of the hand-held phone and that of detector are parallel to the metal bar of the ladder, the detector current becomes the minimum. From these results, it is known that the received intensity changes with an angle of the hand-held phone. Since students use the hand-held phone as they pay attention to its position, the sentence “I found the reason why we need to be cautious when we deal with it” often appears in their lab reports.
of such possibilities, its influence on pacemakers is frequently announced in every public place including trains. We prepared the pacemaker (Fukuda 3077) of the pocket type. This pacemaker is large and can easily be used in a setup of the cycle, the voltage, etc. Connecting a pacemaker’s output terminal to an oscilloscope, the cycle is 70 time/min and the voltage 0.3 volt, as shown in Fig. 8, and observe a normal output waveform, as shown in Fig. 9 (a). Next, the hand-held phone is put to touch the pacemaker. And the hand-held phone is called. Then, a pacemaker’s output waveform changes, as shown in Fig. 9 (b). But if the distance between the cell phone and the pacemaker is 5 cm, the output waveform does not change. Recently, the function of a pacemaker’s filter devices has improved and the influence of a hand-held phone brought to a pacemaker decreases. However, considering the old model’s user and a pacemaker user’s psychology, we have told students, “The restrictions to a hand-held phone are unavoidable.” Furthermore, when using the hand-held phone near the receiver of 7 MHz band which is described later, noise can be heard from the earphone of the receiver. Students have sometime written about the part of this experiment in the lab reports: “If the hand-held phone is called while hearing CD player, noise will enter.” CD player can be called a device of high sensitivity. From these results, even when the frequency of the device differs from that of cellular phones very much, the influence by a hand-held phone is large. In their reports, students answer about the reason of this phenomenon. Since the experiment which demonstrated this answer was in fact not carried out, we can only tell the students that the digital wave of a hand-held phone is made from the wave of various frequencies.

3.2. Experiment of the Modulation Using Radio Frequency Band

Students observe the electromagnetic wave of this frequency directly and next observe its change with information. If the electromagnetic wave of a digital signal is observed, the experimental equipment will become expensive and it is difficult for freshmen to understand it intuitively. Due to these reasons, we did not employ the direct observation of digital signals. Instead, they carry out experiments of the amplitude modulation of an analog wave using a comparatively radio-frequency wave of about 7 MHz. If this frequency band is used, the electromagnetic wave can be directly observed by a cheap oscilloscope as shown in Fig. 10. We prepared the transmitter of the 7 MHz band which can do amplitude modulation, the receiver, an audio frequency oscillator, and an oscilloscope.

First, the electromagnetic wave without modulation is observed. Next, the amplitude modulation is applied by using the sine wave of 200-300 kHz as an information signal, and it is observed with an oscilloscope. The carrier waves modulated are compared with each other as both outputs of the transmitter and those of the receiver, as shown in Fig. 11.
Next the experimenter’s voice is used as the information signal. Amplitude modulation is applied using the outputs of the microphone and the waveforms of both a transmitter and a receiver are observed as in the sine wave modulation.

In this experiment, even though such procedure can easily be performed, there are some students who cannot understand at all that the information is sent due to the modulation.

They say, “It can’t be understood what this experiment does.” There is no other method than explaining them further. In this part, it is worth to observe the analog waveform in spite of the fact that actual cellular phones use a digital modulation. If a budget is enough, actually used digital signals should be observed directly. Even if an understanding of a digital waveform is difficult, students will not misunderstand the experiments at least. Also in the equipments of this high frequency band, the antenna is shortened and the output is made low. Thus the influence to other experiments is also lessened.

3.3. Experiment Using a UHF-TV Antenna

In this experiment, the character of electromagnetic wave of the frequency band of cellular phones is intuitively observed with a commercial UHF-TV antenna. The equipment consists of two such antennas: one is used as the transmitter and another as the receiver. The frequency is about 450 MHz, which is a half of cellular phones frequency band. The receiver is equipped with the ammeter in order to know the relative intensity of the electromagnetic wave which receives.

The parasitic antenna and the wave reflector for the improvement in sensitivity were detached, since a commercial UHF antenna was too large. Thus the sensitivity becomes quite low and reacts only to the electromagnetic wave of a nearby transmitter. Now it is important that the interactions among the experiments at different desks decrease.

![Fig. 10: The modulation experiment of the radio frequency band.](image)

**Fig. 11: The radio frequency (7 MHz) carrier which is modulated by the sine wave.**

The antenna of the receiver is made movable and can catch the direction of the electric field of the electromagnetic wave easily, as shown in Fig. 12. By the direction of these antennas, students can see intuitively that the electromagnetic wave is a polarized transverse wave.

Here, it is better to explain the result of the experiment using Maxwell equation. However, since students who do not belong to either department of physics or that of electrical engineering do not learn electricity and magnetism even if he becomes upperclassmen, we think that it is better, if the instructor can explain a phenomenon qualitatively.

Also, in this part, the metal ladder (mentioned above) is placed between the transmitter and the receiver. Next, the ammeter of the receiver is observed as the metal ladder is rotated.

It is interesting to note that most students have the prejudice of “being easy to pass along an electromagnetic wave from the crevice between metal bars.” But contrary to such expectation, the current of the ammeter becomes the minimum, when antennas are parallel to the metal bar of the ladder, as seen in Fig. 13, and when they are placed perpendicularly, it becomes the maximum.

By explaining this result, the student confirms the relation between the linear polarization and reflection of the electromagnetic wave again.

Since this transmitter of the UHF band can do amplitude modulation by the low frequency, a 450 MHz carrier is modulated using a sound as the signal and transmitted to the receiver. If the output of the receiver with a diode detector is observed by the oscilloscope, the waveform of the sound to be transmitted can be confirmed. We ask the student to ascertain that the information signal does not depend on the wavelengths of the carrier wave in this experiment. But there are some students...
who do not notice that such procedure is in fact the same as the experiment II. In the experiment III the waveform to rectify is observed. Therefore, since the results of the experiments III and II are not in agreement, what we ask students to observe may not be clear.

At first, we also planned the experiment which uses visible light as the carrier wave. However, since experiment time became much too long, we did not finish it.

4. DISCUSSION
This experiment will be evaluated from student's reports and questionnaire. The points to be improved in this experiment are listed as follows.

(1) As mentioned above, there are many students who study the "physics experiment" in a general course. Thus we need to prepare the six such experiment themes in one room. However, in the experiment on the electromagnetic wave, it is impossible to perform the same experiment simultaneously, since the mutual influence is large. So, the wavelength band of an electromagnetic wave would be divided. At least, we had to prepare two wavelength bands for experiments in addition to the wavelength of cellular phones. This means that the contents of the experiment increase. When there are many contents, naturally the experiment action time will become too long.

(2) We believe that the important subject of this experiment would be all of a transverse wave, polarization, reflection, and skin effect. Since the modulation experiment was also included, the points may become less clear and the contents become diversified.

(3) Since there are very few numerical data, it may be hard to prepare good lab reports.

(4) The measurement sometimes becomes unstable by both the mutual influence between experiments and the change in the arrival power from the base station antenna.

The student's evaluations of the experiment of "the everyday physics phenomenon," which we intended at first, were average. Reasons for the lower evaluations in their reports are as follows.

(1) Although the experiment began in an interesting way, it becomes impossible to concentrate gradually since there are too many materials.

(2) Observation is unstable and does not give a result as in the experimental textbook. On the other hand, there are also many comments "I came to consciously use cellular phones which have been usually used unconsciously." Therefore if the result of the experiment becomes clear, we believe that their evaluation of "the theme of the everyday phenomenon" may be improved.

From now on, about the environmental problem of cellular phones and the direct influence to the living body (biological effects), information from the mass media such as television and newspaper is not accepted without consciousness. Some even will begin to appreciate the hardware and the system of cellular phones. It is necessary for the students to think about such things by themselves.

Through the primitive experiment, we hope that students could find out the chaos which underlie the physics phenomenon associated with cellular phones.

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6. REFERENCE