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Experiment for teaching a fundamental principle in electrostatics

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ABSTRACT

According to the theory of electrostatics, the potential difference, or simply "voltage" between two given points in an electrostatic field is a measure of the energy required to move a unit charge between those points. This fundamental principle is usually taught to engineering and physics students in introductory electricity and magnetism (E&M) courses. Unfortunately, experience has shown that students usually have great difficulty grasping that voltage in electrical circuits and systems is actually a measure of energy. This paper describes an advanced experiment that was designed at the University of West Florida for demonstrating the concept practically. In the experiment, a programmable robot arm moves a charged metal plate between two electrodes connected to a voltage source, while a control computer (connected to interface circuitry and a force sensor) directly provides a measurement of the energy exerted in moving the plate. Assessment of the students' understanding of the concept after they perform the experiment has shown an improvement from about 10% (of the total number of students) to nearly 98%.

1. Introduction

The Potential Difference, or simply "voltage", between any two points in an electrostatic field is defined as the "energy required to move a unit charge of one Coulomb between those points" [1,2]. This fundamental principle is typically introduced to students in E&M courses by means of an illustrative figure such as the one shown in Fig. 1.

Experience in interacting with students, however, has shown that students usually have great difficulty grasping that fundamental concept. This, in turn, affects their understanding of related physical concepts, such as the concept of the "electron volt" for example [3]. Hence, entire subjects, such as solid-state physics and quantum mechanics, become inaccessible to the student who has had difficulty grasping that basic concept. To solve this problem, an advanced experiment was designed by the author for demonstrating the concept in Fig. 1 practically; that is, by moving a charge between two metal electrodes connected to a voltage source and directly measuring the energy exerted in moving the charge. Assessment of the students' understanding of the concept after they perform the experiment has shown an improvement from about 10% (of the total population of students in a given class) to nearly 98%. The experiment is described in Section 2. The student assessment data is given in Section 3. Section 4 contains the conclusions.

2. The experiment

2.1. General description

The experimental set up is shown in Fig. 2. As shown, a programmable robot arm carries a miniature, highly sensitive force sensor in its gripper. The force sensor, in turn, carries a circular aluminum plate by means of an insulating Teflon rod that is attached to the input pressure lever of the sensor. The robot that was used is the Microbot Teachmover (a very popular educational robot [4]). The force sensor is the SJR-025 Miniature Force Sensor from Checkline, Inc. [5], which has a resolution of 5×10^{-4} N. The sensor provides its output through the Model BGI Remote Sensor Force Gauge (available from the same manufacturer), which provides a digital readout of the force through an RS232 interface. The miniature force sensor is insensitive to the vertical force (weight of the aluminum plate); it is sensitive only to the horizontal force. In this case, the horizontal force is the electrostatic force that will be acting on the plate, in addition to the air drag.

Typically, the air drag is negligible for speeds less than about 1 m/s [6]; and the horizontal speed of the robot arm is adjusted to be significantly less than 1 m/s. As shown in Fig. 2, the movable aluminum plate, with a diameter of 25 cm, travels between two

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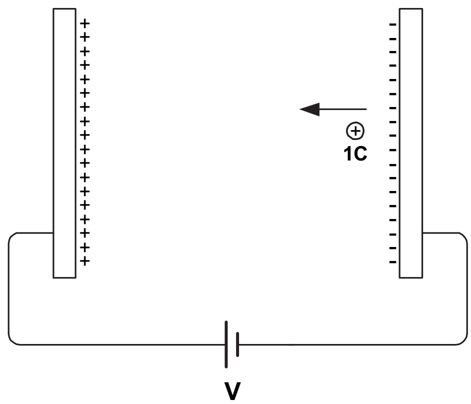

Fig. 1. A DC voltage V is applied between two electrodes. The energy in Joules that is required to move a positive charge of 1 C against the field from the negative electrode to the positive electrode is precisely equal to V.

fixed aluminum plates of similar dimensions. The surfaces of the fixed plates are covered with a very thin sheet of Polystyrene (an excellent dielectric and insulator), so that no transfer of charge will occur between the fixed plates and the movable plate when the latter comes in contact with the fixed plates. Originally, the movable plate will be in contact with the grounded fixed plate that is shown in Fig. 2, when the robot arm is at its home position. At that position, a small DC voltage of 12 V is applied between the movable and the fixed plates so that the movable plate will acquire a charge. The student can calculate the charge Q on the plate from the well-known equation [1]

$$Q = C\Delta V \tag{1}$$

where C is the capacitance between the two plates. The capacitance C is first calculated from the other well-known equation [1]

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \tag{2}$$

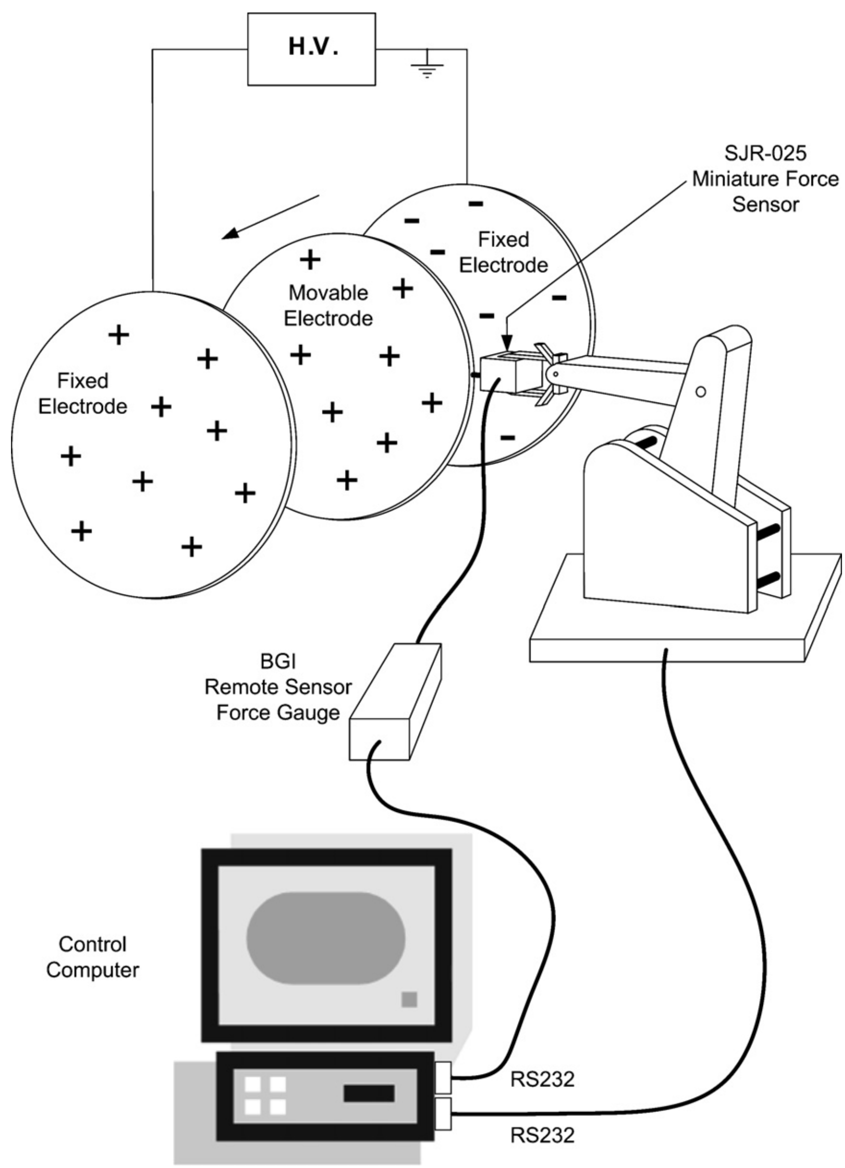

Fig. 2. A programmable robot arm transports a charged metal plate between two electrodes connected to a source of high voltage. A highly accurate force meter provides a digital readout of the force acting on the plate, which is fed to the RS232 port of a control computer. The control computer commands the robot's gripper to travel on a straight line, while acquiring the x position of the gripper in real time via a second RS232 port. The control computer finally performs numerical integration and calculates the energy exerted in transporting the plate.