Experiment 321.
Displaying the equipotential lines of electric fields

Objects of the experiment

- Investigate the space between a pair of electrodes that are connected to a source of current.
- Plot and examine the plot in terms of the implied electric field.

Equipment

Electrolytic tank	1 pts.	54509
Low-voltage power supply	1 pts.	521231
Multimeter LDanalog 20	1 pts.	531120
Connecting leads100 cm, red/blue, pair	2 pts.	50146
Probe	1 pts.	

Principles

Electric charge

The ancient Greeks noted that rubbing a piece of amber endowed it with strange properties including the ability to attract light objects such as hair. Indeed the word "electricity" derives from the Greek *elektron* meaning amber.

Later experiments, especially in the 18th century, established that many materials exhibit such properties and that there are 'two kinds of electricity'. Objects with the same kind repel each other; objects with different kinds attract each other. The 'two kinds of electricity' can also neutralize each other if brought together and for this reason them labelled positive and negative. The quantity of either kind of electricity in a body is now known as the *electric charge* of the body and may be expressed as a multiple of the SI unit of charge, the *coulomb* (C).

Twentieth-century experiments demonstrated that electric charge is quantized; that is, it comes in integer multiples of individual small units called the elementary charge, e, approximately equal to $1{,}602 \cdot 10^{-19}$ C. The proton has a charge of $+e$, and the electron has a charge of $-e$.

Coulomb's law and electrostatic forces

The nature of the force between charges was first investigated by Charles Augustin de Coulomb (1736–1806) in 1785. In a series of painstaking experiments he looked at the way in which the force between charged bodies varies with their separation and with the size and sign of the charge. His work resulted in Coulomb's law which can be stated as follows:

> The magnitude of the electric force F_{el} between two point charges q_1 and q_2 is proportional to the product of their charges and inversely proportional to the square of the distance r between them. The force is directed along a line joining the particles and is repulsive for charges of the same sign and attractive for charges of opposite sign:

$$F_{el} = \frac{1}{4\pi\varepsilon_0} \frac{|q_1 q_2|}{r^2} . \tag{1}$$

Note that F_{el} is a magnitude, and therefore a positive quantity, that is why Equation 1a involves the modulus $|q_1 q_2|$ which is positive, rather than simply $q_1 q_2$ which might be positive or negative. Of course, to describe the Coulomb force fully, we need to specify its direction as well as its magnitude. We can do this by introducing a vector $\mathbf{r}$ that points from q_1 to q_2. By dividing the vector $\mathbf{r}$ by its own magnitude r, we obtain the unit vector points in the same direction as $\mathbf{r}$ (i.e. from q_1 to q_2. Using the vector $\mathbf{r}$ we can write the electrostatic force on q_2 due to q_1 as

$$\mathbf{F}_{el} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \frac{\mathbf{r}}{r} . \tag{2}$$

ε_0 – electric constant,is an ideal, (baseline) physical constant. Its value is

$$\varepsilon_0 = \frac{1}{\mu_0 c^2} = \frac{1}{4\pi 10^{-7} \times 299792458^2} \approx 8{,}85 \cdot 10^{-12}\ \text{F/m} \quad \text{(farads per meter)} . \tag{3}$$

The presence of a medium reduces the force by a factor $1/\varepsilon$, where ε (a dimensionless number, greater than 1) is the called relative permittivity of the medium. For example, air has a relative permittivity of $\varepsilon = 1{,}005$.

Coulomb forces, like all other forces, are vectors and therefore they can be added according to the normal rules of vector addition. To find the force on a particular charged body due to a number of other charged bodies, we simply add the individual Coulomb forces vectorially.

Electric field

The concept of electric fields was introduced by Michael Faraday. One way to look at the force between charges is to say that the charge alters the space around it by generating an electric field $\mathbf{E}$. Any other charge placed in this field then experiences a Coulomb force. We thus regard the **E** field as transmitting the Coulomb force.

To define the electric field **E** more precisely, consider a small positive test charge q at a given location. As long as everything else stays the same, the Coulomb force exerted on the test charge q is proportional to q. Then the force per unit charge, $\mathbf{F}/\mathbf{q}$, does not depend on the charge q, and therefore can be regarded meaningfully to be the electric field **E** at that point:

$$\mathbf{E} = \frac{\mathbf{E}}{q}\,. \tag{4}$$

Closely associated with the concept of electric field is the pictorial representation of the field in terms of *lines of force*. These are imaginary geometric lines constructed so that the direction of the line, as given by the tangent to the line at each point, is always in the direction of the **E** field at that point, or equivalently, is in the direction of the force that would act on a small positive test charge placed at that point. The electric field and the concept of lines of electric force can be used to map out what forces act on a charge placed in a particular region of space.

Electric potential

The electric potential difference $\Delta\varphi$ between two points is defined as the work A required to move a small positive test charge q from one point to the other divided by the test charge, i.e.,

$$\Delta\varphi = \frac{A}{q}\,. \tag{5}$$

The work and hence the potential difference between the two points is *independent* of the path that is taken between the two points. Since the potential at one of the points may be arbitrarily set equal to zero, the potential difference and potential at the other point are the same. Using the basic definition of work, in which work A equals force **F** times distance $\Delta\mathbf{r}$ or

$$A = \mathbf{F} \cdot \Delta\mathbf{r}\,. \tag{6}$$

a relationship between the electric potential φ and the electric field strength **E** can be found. While work and potential difference are scalar quantities and are independent of the direction and path that is taken, the electric field strength is a vector quantity and depends on the direction of the force.

$$\Delta\varphi = \frac{\mathbf{F} \cdot \Delta\mathbf{r}}{q} = \mathbf{E} \cdot \Delta\mathbf{r}\,. \tag{7}$$

If **E** and $\Delta\mathbf{r}$ are in the same direction, then

$$E = \frac{\Delta\varphi}{\Delta r}\,. \tag{8}$$

For situations where the electric field is not uniform at different points in space, this equation must be constrained to apply over a small increment of distance $d\mathbf{r}$ where the change in potential is $d\varphi$. Then the electric potential is found by the following equation

$$\Delta\varphi = \int d\varphi = \int \mathbf{E} \cdot d\mathbf{r} \,. \tag{9}$$

The electric field's direction is *parallel* and *opposite* to the direction in which the electric potential increases the most. In calculus, an operator called the *gradient* and symbolized by ∇ is introduced to signify changes that must be made in a direction in which the change is greatest. With this notation Equation (10) may be written in terms of calculus so that

$$\mathbf{E} = -\nabla\varphi \,. \tag{10}$$

The minus sign occurs because the electric field is in the opposite direction to the direction in which the potential is increasing.

Conclusion

- An electric field is a region in space where one charge experiences a force from another charge.
- Electric potential is the amount of energy stored in an electric charge due to its position in an electric field.
- The strength of an electric field is directly related to the magnitude of the electric charge producing the field.
- Electric field lines begin on positive charges and radiate away from them toward negative charges, where they terminate.
- Equipotential lines are lines connecting points of the same electric potential. All electric field lines cross all equipotential lines perpendicularly.

Setup

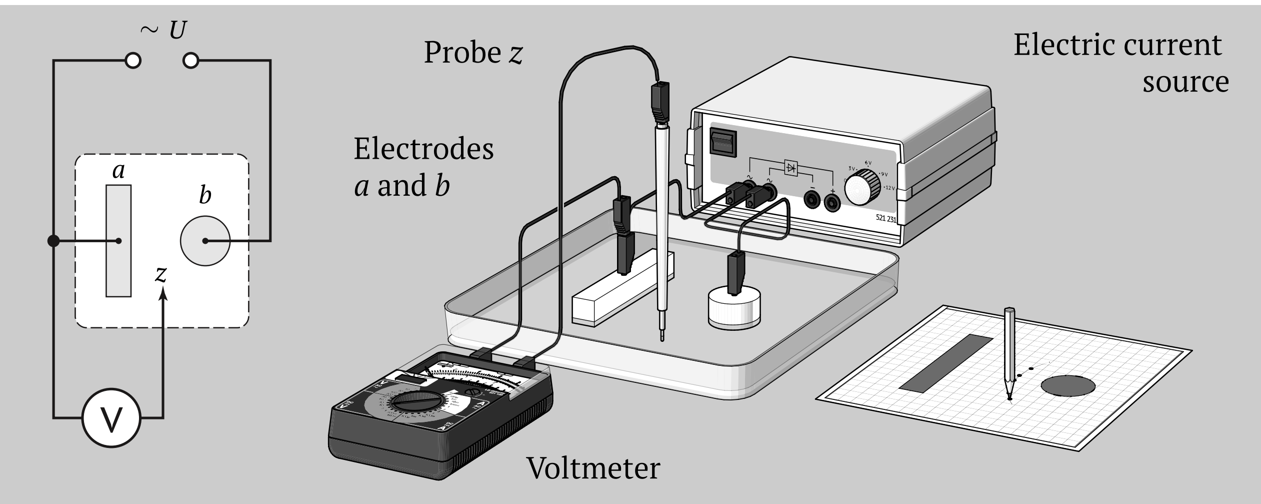

Figure 1. Experimental setup.

In this experiment, the concept of electric field will be developed by investigating the space between a pair electrodes connected to a source of current. To do this, a voltage is applied to a pair of electrodes placed in an electrolytic tray filled with distilled water. An AC voltage is used to avoid potential shifts due to electrolysis at the electrodes. A voltmeter measures the potential difference between the electrode and a needle immersed in the water. To display the isoelectric lines, the points of equal potential difference are localized and drawn on graph paper.

Carrying out the experiment

- Set in tank one of a pair of electrodes a and b, as directed by the teacher. Assemble the circuit as shown in Figure 1. Set the limits of measurement AC,10 V on voltmeter by turning the knob switch.
- Take a sheet of graph paper and mark the position of the investigated electrodes on it.
- Pour a thin layer(3 ... 5 mm) of water in the vessel.
- Turn on the AC power supply[1].
- Move the probe around electrode a until you find a point at 1 V potential. Note that point on a sheet graphic paper and repeat this procedure many times until you can construct with certainty the 1 V equipotential line. Don't be afraid to go around behind the electrodes to measure the potential and find points. Connect the points with a solid line.
- Repeat the previous step for the 2, 3, 4, 5, 6, 7, 8, and 9 volt equipotential lines
- Draw continuous dotted lines perpendicularly to the equipotential lines and indicate the direction of the electric field lines.
- Have your techer designate points on your graph at which you are to calculate the magnitude of the electric field strength.. Label them as $A, B, C, \ldots$
- Calculate the electric field strength at one of the indicated points by moving a little distance (less than 0,5 cm) to the left along the electric field line and a little distance to the right along the electric field line. Record the electric potential at each of these adjacent points and find their difference, $\Delta\varphi$. Measure the distance between the two points to find Δr. Calculate the electric field strength by dividing $\Delta\varphi$ by Δr. Repeat for each of the other points. Record your results for the points $A, B, C, \ldots$
- Repeat the experiment for another electrode configuration
- After you have completed the experiment, turn off the power supply and the voltmeter.

[1] You are authorized to switch on the power supply only after checking the electrical circuit by teacher.