The Electric Potential

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Potential Energy

Recall that the change potential energy is defined as the negative of the work done by a conservative force:

$$\Delta \mathsf{PE} = \mathsf{PE}_\mathsf{F} - \mathsf{PE}_\mathsf{I} = -W$$

The potential energy is a scalar quantity.
The electrostatic (Coulomb) is also conservative, therefore an electrical potential energy function can be associated with the electrostatic force.

Work Done In An Electric Field

Consider a uniform electric field **E**, but in one dimension. Let the field is directed along the positive x-axis.
Let a charge move from an initial point A in the electric field to a final point B, in the direction of the field.
The charge moves because of the electrostatic force acting on it (due to the electric field).

Work Done In An Electric Field

The work done on the charge is equal to the electrostatic force times the displacement:

$$W_{AB} = F\Delta x = qE(x_{\mathsf{F}} - x_{\mathsf{I}})$$

Note that Δx can be positive or negative, since it is a vector and depends on direction. The charge q can also be positive or negative, depending on what type of charge it is.

Work Done And The Potential Difference

When work is done on a charge in moving it from point A to point B

- A and B are at the same potential if $W_{AB} = 0$,
- A and B are at different potentials if $W_{AB} \neq 0$, i.e. there is a potential difference between the two points.

The potential difference ΔV between points A and B in an electrostatic field is defined as the work done per unit charge, that is done on *any* charge, to move it slowly from A to B.

$$\Delta V = \frac{W_{AB}}{q}$$

The SI unit of potential difference is the Volt, V (1 V = 1 J C^{-1}).
The potential difference ΔV is the difference in electric potential between points A and B:

$$\Delta V = V_B - V_A$$

Ohm's Law and Resistance

Current is the rate of flow of charge.

$$I = \frac{\Delta q}{\Delta t}$$

Current moves along a circuit (and across a component) when there is a potential difference.
A battery is a source electrical potential energy, so that a charge can move around a circuit.
Consider a current moving through a component in a circuit. Electrons collide with the fixed atoms in the component, and lose some of their kinetic energy to the atoms. The vibrational kinetic energy of the atoms increase (and hence the temperature of the component increases).

Ohm's Law and Resistance

Ohm's Law says that, for a wide range of potential differences, the potential difference (voltage drop) ΔV across a conductor (component) is proportional to the current I through the conductor.

$$\begin{aligned} \Delta V &\propto I \\ \Delta V &= IR \end{aligned}$$

R is the *resistance*. The SI units for voltage, current and resistance are the Volt (V), Ampere (A) and Ohm (Ω), respectively.
The resistance R of a conductor is defined as the ratio of the voltage across the conductor and the current through the conductor.

$$R = \frac{\Delta V}{I}$$

where $1\,\Omega = 1\,\mathrm{V\,A^{-1}}$.

Prac 2 A

The circuit will have a variable voltage source in series with a resistor.
Record six pairs of voltages (potential differences) and currents across/through the resistor.
Plot a graph of ΔV vs I, to find the value of the resistance R.

Voltage Sources

A voltage source (like a battery) should ideally have no resistance itself.

The voltage source in a circuit is referred to an emf. An emf provides a potential energy per unit charge (like a ”charge pump”), to maintain current flowing through a closed circuit.

Real voltage sources like batteries always have some small *internal resistance* r. Measuring the voltage ΔV across a battery will show that ΔV is not equal to the emf $\mathcal{E}$.

The difference comes from the voltage drop across the internal resistance of the emf.

Prac 2 B

The circuit consists of an emf (a battery) in series with a variable resistor.
The voltage drop ΔV across the battery is related to the resistance R of the resistor by

$$\frac{1}{V} = \frac{r}{\mathcal{E}}\frac{1}{R} + \frac{1}{\mathcal{E}}$$

For ten different values of R, record the voltage ΔV.
Use the equation to plot a straight-line graph. Use the graph to find the values for the internal resistance r and the emf $\mathcal{E}$.

Resistance And Resistivity

Charges lose energy as they collide with atoms in a resistor.
The resistance of a resistor increases with length, since there are more atoms for the electrons to collide with.
The resistance increases for a smaller cross-sectional area, and decreases as the cross-sectional area increases.
The resistance R is given by

$$R = \rho \frac{l}{A}$$

where ρ is the resistivity of the material, l is its length and A is its cross-sectional area.
Good electric conductors have a very low resistivity.

Prac 3 A

A Wheatstone bridge circuit is used to find the value of one unknown resistance, given three other known resistances which are adjustable.
A slide-wire form of the Wheatstone bridge is used.
The known resistances are varied so that there is no current flowing through the galvanometer (G). The unknown resistor R_1 can be found from the known resistors as follows:

$$R_1 = R_3 \frac{R_2}{R_4}$$