3.S: Electric Potential (Summary)

Key Terms

electric dipole	system of two equal but opposite charges a fixed distance apart
electric dipole moment	quantity defined as $\vec{p} = q\vec{d}$ for all dipoles, where the vector points from the negative to positive charge
electric potential	potential energy per unit charge
electric potential difference	the change in potential energy of a charge q moved between two points, divided by the charge.
electric potential energy	potential energy stored in a system of charged objects due to the charges
electron-volt	energy given to a fundamental charge accelerated through a potential difference of one volt
electrostatic precipitators	filters that apply charges to particles in the air, then attract those charges to a filter, removing them from the airstream
equipotential line	two-dimensional representation of an equipotential surface
equipotential surface	surface (usually in three dimensions) on which all points are at the same potential
grounding	process of attaching a conductor to the earth to ensure that there is no potential difference between it and Earth
ink jet printer	small ink droplets sprayed with an electric charge are controlled by electrostatic plates to create images on paper
photoconductor	substance that is an insulator until it is exposed to light, when it becomes a conductor
Van de Graaff generator	machine that produces a large amount of excess charge, used for experiments with high voltage
voltage	change in potential energy of a charge moved from one point to another, divided by the charge; units of potential difference are joules per coulomb, known as volt
xerography	dry copying process based on electrostatics

Key Equations

Potential energy of a two-charge system	$U(r) = k\frac{qQ}{r}$
Work done to assemble a system of charges	$W_{12\cdots N} = \frac{k}{2}\sum_i^N\sum_j^N \frac{q_iq_j}{r_{ij}}$ for $i \neq j$
Potential difference	$\Delta V = \frac{\Delta U}{q}$ or $\Delta U = q\Delta V$
Electric potential	$V = \frac{U}{q} = -\int_R^P \vec{E}\cdot\vec{dl}$
Potential difference between two points	$\Delta V_{AB} = V_B - V_A = -\int_A^B \vec{E}\cdot\vec{dl}$
Electric potential of a point charge	$V = \frac{kq}{r}$

Electric potential of a system of point charges	$V_P = k\sum_1^N \frac{q_i}{r_i}$
Electric dipole moment	$\vec{p} = q\vec{d}$
Electric potential due to a dipole	$V_P = k\frac{\vec{p}\cdot\hat{r}}{r^2}$
Electric potential of a continuous charge distribution	$V_P = k\int \frac{dq}{r}$
Electric field components	$E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$
Del operator in Cartesian coordinates	$\vec{\nabla} = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$
Electric field as gradient of potential	$\vec{E} = -\vec{\nabla}V$
Del operator in cylindrical coordinates	$\vec{\nabla} = \hat{r}\frac{\partial}{\partial r} + \hat{\varphi}\frac{1}{r}\frac{\partial}{\partial \varphi} + \hat{z}\frac{\partial}{\partial z}$
Del operator in spherical coordinates	$\vec{\nabla} = \hat{r}\frac{\partial}{\partial r} + \hat{\theta}\frac{1}{r}\frac{\partial}{\partial \theta} + \hat{\varphi}\frac{1}{r\sin\theta}\frac{\partial}{\partial \varphi}$

Summary

7.2 Electric Potential Energy

- The work done to move a charge from point A to B in an electric field is path independent, and the work around a closed path is zero. Therefore, the electric field and electric force are conservative.
- We can define an electric potential energy, which between point charges is $U(r) = k\frac{qQ}{r}$, with the zero reference taken to be at infinity.
- The superposition principle holds for electric potential energy; the potential energy of a system of multiple charges is the sum of the potential energies of the individual pairs.

7.3 Electric Potential and Potential Difference

- Electric potential is potential energy per unit charge.
- The potential difference between points A and B, $V_B - V_A$, that is, the change in potential of a charge q moved from A to B, is equal to the change in potential energy divided by the charge.
- Potential difference is commonly called voltage, represented by the symbol ΔV:

$$\Delta V = \frac{\Delta U}{q} \text{ or } \Delta U = q\Delta V.$$

- An electron-volt is the energy given to a fundamental charge accelerated through a potential difference of 1 V. In equation form,

$$1\,\text{eV} = (1.60\times10^{-19}\,\text{C})(1\,\text{V}) = (1.60\times10^{-19}\,C)(1\,\text{J/C}) = 1.60\times10^{-19}\,\text{J}.$$

7.4 Calculations of Electric Potential

- Electric potential is a scalar whereas electric field is a vector.
- Addition of voltages as numbers gives the voltage due to a combination of point charges, allowing us to use the principle of superposition: $V_P = k\sum_1^N \frac{q_i}{r_i}$.
- An electric dipole consists of two equal and opposite charges a fixed distance apart, with a dipole moment $\vec{p} = q\vec{d}$.
- Continuous charge distributions may be calculated with $V_P = k\int\frac{dq}{r}$.

7.5 Determining Field from Potential

- Just as we may integrate over the electric field to calculate the potential, we may take the derivative of the potential to calculate the electric field.

- This may be done for individual components of the electric field, or we may calculate the entire electric field vector with the gradient operator.

7.6 Equipotential Surfaces and Conductors

- An equipotential surface is the collection of points in space that are all at the same potential. Equipotential lines are the two-dimensional representation of equipotential surfaces.
- Equipotential surfaces are always perpendicular to electric field lines.
- Conductors in static equilibrium are equipotential surfaces.
- Topographic maps may be thought of as showing gravitational equipotential lines.

7.7 Applications of Electrostatics

- Electrostatics is the study of electric fields in static equilibrium.
- In addition to research using equipment such as a Van de Graaff generator, many practical applications of electrostatics exist, including photocopiers, laser printers, ink jet printers, and electrostatic air filters.
