4.S: Summary

Key Terms

electric dipole	system of two equal but opposite charges a fixed distance apart
electric dipole moment	quantity defined as $\{vecp = q\vec{d}$ 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
capacitance	amount of charge stored per unit volt
capacitor	device that stores electrical charge and electrical energy
dielectric	insulating material used to fill the space between two plates
dielectric breakdown	phenomenon that occurs when an insulator becomes a conductor in a strong electrical field
dielectric constant	factor by which capacitance increases when a dielectric is inserted between the plates of a capacitor
dielectric strength	critical electrical field strength above which molecules in insulator begin to break down and the insulator starts to conduct
energy density	energy stored in a capacitor divided by the volume between the plates
induced electric-dipole moment	dipole moment that a nonpolar molecule may acquire when it is placed in an electrical field

induced electrical field	electrical field in the dielectric due to the presence of induced charges
induced surface charges	charges that occur on a dielectric surface due to its polarization
parallel combination	components in a circuit arranged with one side of each component connected to one side of the circuit and the other sides of the components connected to the other side of the circuit
parallel-plate capacitor	system of two identical parallel conducting plates separated by a distance
series combination	components in a circuit arranged in a row one after the other in a circuit

Key Equations

Potential energy of a two-charge system	$U(r) = k\frac{qQ}{r}$
Work done to assemble a system of charges	$W_{12 \cdots N} = \frac{k}{2}\sum_{i}^{N}\sum_{j}^{N}\frac{q_i q_j}{r_{ij}}$ 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	$\vec{\nabla} = \hat{r}\frac{\partial}{\partial r} + \hat{\theta}\frac{1}{r}\frac{\partial}{\partial\theta} + \hat{\varphi}\frac{1}{r sin\theta}\frac{\partial}{\partial\varphi}$
Capacitance	$C = \frac{Q}{V}$
Capacitance of a parallel-plate capacitor	$C = \varepsilon_0\frac{A}{d}$
Capacitance of a vacuum spherical capacitor	$C = 4\pi\varepsilon_0\frac{R_1 R_2}{R_2 - R_1}$

Capacitance of a vacuum cylindrical capacitor	$C=\frac{2\pi\varepsilon_0 l}{ln(R_2/R_1)}$
Capacitance of a series combination	$\frac{1}{C_S}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\cdots$
Capacitance of a parallel combination	$C_P=C_1+C_2+C_3+\cdots$
Energy density	$u_E=\frac{1}{2}\varepsilon_0 E^2$
Energy stored in a capacitor	$U_C=\frac{1}{2}V^2C=\frac{1}{2}\frac{Q^2}{C}=\frac{1}{2}QV$
Capacitance of a capacitor with dielectric	$C=\kappa C_0$
Energy stored in an isolated capacitor with dielectric	$U=\frac{1}{\kappa}U_0$
Dielectric constant	$\kappa=\frac{E_0}{E}$
Induced electrical field in a dielectric	$\vec{E}_i=(\frac{1}{\kappa}-1)\vec{E}_0$

Summary

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.

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,

$$1eV=(1.60\times 10^{-19}C)(1V)=(1.60\times 10^{-19}C)(1J/C)=1.60\times 10^{-19}J$$ ..

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: \(\displaystyle 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 $V_P=k\int\frac{dq}{r}$.

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.

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.

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.

Capacitors and Capacitance

- A capacitor is a device that stores an electrical charge and electrical energy. The amount of charge a vacuum capacitor can store depends on two major factors: the voltage applied and the capacitor's physical characteristics, such as its size and geometry.
- The capacitance of a capacitor is a parameter that tells us how much charge can be stored in the capacitor per unit potential difference between its plates. Capacitance of a system of conductors depends only on the geometry of their arrangement and physical properties of the insulating material that fills the space between the conductors. The unit of capacitance is the farad, where $1F = 1C/1V$.

Capacitors in Series and in Parallel

- When several capacitors are connected in a series combination, the reciprocal of the equivalent capacitance is the sum of the reciprocals of the individual capacitances.
- When several capacitors are connected in a parallel combination, the equivalent capacitance is the sum of the individual capacitances.
- When a network of capacitors contains a combination of series and parallel connections, we identify the series and parallel networks, and compute their equivalent capacitances step by step until the entire network becomes reduced to one equivalent capacitance.

Energy Stored in a Capacitor

- Capacitors are used to supply energy to a variety of devices, including defibrillators, microelectronics such as calculators, and flash lamps.
- The energy stored in a capacitor is the work required to charge the capacitor, beginning with no charge on its plates. The energy is stored in the electrical field in the space between the capacitor plates. It depends on the amount of electrical charge on the plates and on the potential difference between the plates.
- The energy stored in a capacitor network is the sum of the energies stored on individual capacitors in the network. It can be computed as the energy stored in the equivalent capacitor of the network.

Capacitor with a Dielectric

- The capacitance of an empty capacitor is increased by a factor of κ when the space between its plates is completely filled by a dielectric with dielectric constant κ.
- Each dielectric material has its specific dielectric constant.
- The energy stored in an empty isolated capacitor is decreased by a factor of κκ when the space between its plates is completely filled with a dielectric with dielectric constant κ.
