<table>
<thead>
<tr>
<th>Force and Field</th>
<th>$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{Q_1Q_2}{r^2} \hat{r}$</th>
<th>$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r^2} \hat{r}$</th>
<th>$\vec{F}_{12} = Q_2 \vec{E}_1 = Q_2 \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r^2} \hat{r}$</th>
</tr>
</thead>
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<tr>
<td>Pot. Energy and Voltage</td>
<td>$U_{12} = \frac{1}{4\pi\varepsilon_0} \frac{Q_1Q_2}{r}$</td>
<td>$V_1 = \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r}$</td>
<td>$U_{12} = Q_2V_1 = Q_2 \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r}$</td>
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</table>

Potential energy: $\Delta U = -W_{\text{Field}} = W_{\text{External}}$

Gauss’s Law: $\int \vec{E} d\vec{A} = \frac{Q_{\text{inside}}}{\varepsilon_0}$

Field and Voltage: $\vec{E} = \left( -\frac{\partial V}{\partial x}, -\frac{\partial V}{\partial y}, -\frac{\partial V}{\partial z} \right)$ \quad In a uniform field: $V = -Ed$

Capacitance: $C = \frac{Q}{V}$ \hspace{1cm} Parallel plate capacitor: $C = \varepsilon_0 \frac{A}{d}$; $E = \frac{\sigma}{\varepsilon_0}$

Capacitor in series: $\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$ \quad Capacitors in parallel: $C_{eq} = \sum_i C_i$

Energy: $U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$ \quad and $u = \frac{1}{2} \varepsilon E^2$

Current: $I = \frac{dQ}{dt} = n |q| v_d A$ \quad and $j = \frac{I}{A} = n |q| v_d$

Ohm’s Law: $V = IR$ \quad and $E = J\sigma = \frac{j}{\sigma}$ \quad with $R = \rho \frac{L}{A}$

Power: $P = IV = I^2 R = \frac{V^2}{R}$

Resistors in series: $R_{eq} = \sum_i R_i$ \quad Resistors in parallel: $\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$

Kirchhoff’s rules: $\sum I = 0$ (Junction rule); $\sum V = 0$ (Loop rule)

Capacitor charging: $Q = Q_f \left( 1 - e^{-\frac{t}{RC}} \right)$ \quad and $I = I_o e^{-\frac{t}{RC}} \quad$ with $Q_f = VC$; $I_o = \frac{V}{R}$
Kirchhoff’s conventions:

If your loop goes through a battery from – to + the Voltage increases (e.g. $\Delta V = +12$ V)

If your loop goes through a battery from + to – the Voltage decreases (e.g. $\Delta V = -12$ V)

If you go across a resistor and the loop direction and guessed current direction are the same, the voltage decreases (e.g. $\Delta V = -iR$)

If you go across a resistor and the loop direction and guessed current direction are opposite, the voltage increases (e.g. $\Delta V = +iR$)
Units and constants:

\[ \varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 / \text{N.m}^2 \quad \text{and} \quad \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \text{ N.m}^2 / \text{C}^2 \]

\[ e = 1.602 \times 10^{-19} \text{ C} \]

[Charge]=Coulomb=C
[Electric Force]=Newton=N
[Electric Field]=[Force]/[Charge]=N/C=[Voltage]/[distance]=Volt/meter= V/m
[Energy]=Newton.meter=Joule=J
[Voltage]=[Energy]/[Charge]=J/C=Volt=V
[Capacitance] = [Charge]/[Voltage]=Coulomb/Volt=C/V=Farad=F
[Current] = [Charge]/[time]=Coulomb/sec.=C/s=Amp=A
[Resistance] = [Voltage]/[Current]=Volt/Amp= Ohm=Ω