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Chapter 3 Special Techniques

Problem 3.1
The argument is exactly the same as in Sect. 3.1.4, except that since $r < R$, $\sqrt{r^2 + R^2 - 2rR} = (R - r)$, instead of $(r - R)$. Hence $V_{\text{int}} = \frac{\rho}{4\pi\epsilon_0} \int_0^{2\pi} \int_0^\pi \int_0^R \frac{1}{(R - r)} r^2 dr d\theta d\phi$. If there is more than one charge inside the sphere, the average potential due to interior charges is $\frac{1}{4\pi\epsilon_0} \frac{Q_{\text{int}}}{R}$, and the average due to exterior charges is $V_{\text{ext}} = \frac{Q_{\text{ext}}}{4\pi\epsilon_0 R}$. \checkmark

Problem 3.2
A stable equilibrium is a point of local minimum in the potential energy. Here the potential energy is qV . But we know that Laplace's equation allows no local minima for V . What looks like a minimum, in the figure, must in fact be a saddle point, and the best "nudge" through the center of each face.

Problem 3.3
Laplace's equation in spherical coordinates, for V dependent only on r , reads
$$\nabla^2 V = \frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{dV}{dr} \right) = 0 \Rightarrow r^2 \frac{dV}{dr} = c (\text{constant}) \Rightarrow \frac{dV}{dr} = \frac{c}{r^2} \Rightarrow V = -\frac{c}{r} + k.$$

Example: potential of a uniformly charged sphere
In spherical coordinates: $\nabla^2 V = \frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{dV}{dr} \right) = 0 \Rightarrow \frac{dV}{dr} = c \Rightarrow \frac{dV}{dr} = \frac{c}{r} \Rightarrow V = c \ln r + k.$

Example: potential of a long wire
Problem 3.4
Same as proof of second uniqueness theorem, up to the equation $\oint_S \mathbf{E}_1 \cdot \mathbf{E}_2 \cdot d\mathbf{a} = - \int_V (\rho_1 E_2)^2 d\tau$. But on each surface, either $V_1 = 0$ (if S is specified on the surface), or else $\mathbf{E}_1 = 0$ (if $\mathbf{E}_1 = -\nabla V_1 = -\mathbf{E}_2$, is specified). So $\int_V (\rho_1 E_2)^2 d\tau = 0$, and hence $\mathbf{E}_1 = \mathbf{E}_2$. \square

Problem 3.5
Putting $V = T + V_1$ into Green's identity:
$$\int_V (\nabla^2 T + \nabla^2 V_1 + \nabla^2 V_1) d\tau = \int_V (\nabla^2 T + \nabla^2 V_1) d\tau = \int_V \nabla^2 T d\tau = -\frac{\rho}{\epsilon_0} \int_V d\tau = -\frac{Q}{\epsilon_0}.$$

So $\int_V \nabla^2 T d\tau = -\frac{Q}{\epsilon_0} - \int_V \nabla^2 V_1 d\tau$, and the rest is the same as before.

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