We require $|E_x| = -|2E_y|$, so 2(y + 2) = 5. Thus y = 1/2, and the field becomes:

$$\mathbf{E}_{z=0} = \frac{\rho_t}{2\pi\epsilon_0} \left[\frac{2.5\mathbf{a}_y - 5\mathbf{a}_z}{(2.5)^2 + 25} \right] = \frac{23\mathbf{a}_y - 46\mathbf{a}_z}{2\pi\epsilon_0}$$

2.18. a) Find E in the plane z = 0 that is produced by a uniform line charge, ρ_L, extending along the z axis over the range −L < z < L in a cylindrical coordinate system: We find E through</p>

$$\mathbf{E} = \int_{-L}^{L} \frac{\rho_L dz (\mathbf{r} - \mathbf{r}')}{4\pi\epsilon_0 |\mathbf{r} - \mathbf{r}'|^3}$$

where the observation point position vector is $\mathbf{r} = \rho \mathbf{a}_{\rho}$ (anywhere in the x-y plane), and where the position vector that locates any differential charge element on the z axis is $\mathbf{r}' = z\mathbf{a}_z$. So $\mathbf{r} - \mathbf{r}' = \rho \mathbf{a}_{\rho} - z\mathbf{a}_z$, and $|\mathbf{r} - \mathbf{r}'| = (\rho^2 + z^2)^{1/2}$. These relations are substituted into the integral to yield:

$$\mathbf{E} = \int_{-L}^{L} \frac{\rho_L dz (\rho \mathbf{a}_{\rho} - z \mathbf{a}_{z})}{4\pi \epsilon_0 (\rho^2 + z^2)^{3/2}} = \frac{\rho_L \, \rho \, \mathbf{a}_{\rho}}{4\pi \epsilon_0} \int_{-L}^{L} \frac{dz}{(\rho^2 + z^2)^{3/2}} = E_{\rho} \, \mathbf{a}_{\rho}$$

Note that the second term in the left-hand integral (involving za_x) has effectively vanished because it produces equal and opposite sign contributions when the integral is taken over symmetric limits (odd parity). Evaluating the integral results in

$$E_{\rho} = \frac{\rho_L \rho}{4\pi\epsilon_0} \frac{z}{\rho^2 \sqrt{\rho^2 + z^2}} \Big|_{-L}^{L} = \frac{\rho_L}{2\pi\epsilon_0 \rho} \frac{L}{\sqrt{\rho^2 + L^2}} = \frac{\rho_L}{2\pi\epsilon_0 \rho} \frac{1}{\sqrt{1 + (\rho/L)^2}}$$

Note that as $L \to \infty$, the expression reduces to the expected field of the infinite line charge in free space, $\rho_L/(2\pi\epsilon_0 \rho)$.

b) if the finite line charge is approximated by an infinite line charge $(L \to \infty)$, by what percentage is E_ρ in error if $\rho = 0.5L$? The percent error in this situation will be

$$\% \text{ error} = \left[1 - \frac{1}{\sqrt{1 + (\rho/L)^2}}\right] \times 100$$

For $\rho = 0.5L$, this becomes % error = 10.6 %

- c) repeat b with ρ = 0.1L. For this value, obtain % error = 0.496 %.
- 2.19. A uniform line charge of 2 μC/m is located on the z axis. Find E in rectangular coordinates at P(1, 2, 3) if the charge extends from
 - a) −∞ < z < ∞: With the infinite line, we know that the field will have only a radial component in cylindrical coordinates (or x and y components in cartesian). The field from an infinite line on the z axis is generally E = [ρ_l/(2πε₀ρ)]a_ρ. Therefore, at point P:

$$\mathbf{E}_{P} = \frac{\rho_{l}}{2\pi\epsilon_{0}} \frac{\mathbf{R}_{xP}}{|\mathbf{R}_{xP}|^{2}} = \frac{(2 \times 10^{-6})}{2\pi\epsilon_{0}} \ \frac{\mathbf{a}_{x} + 2\mathbf{a}_{y}}{5} = 7.2\mathbf{a}_{x} + 14.4\mathbf{a}_{y} \ \text{kV/m}$$

where \mathbf{R}_{zP} is the vector that extends from the line charge to point P, and is perpendicular to the z axis; i.e., $\mathbf{R}_{zP} = (1, 2, 3) - (0, 0, 3) = (1, 2, 0)$.

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