Halliday ♦ Resnick ♦ Walker

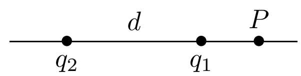
FUNDAMENTALS OF PHYSICS
SIXTH EDITION

Selected Solutions

Chapter 23

23.9
23.23
23.41

9. At points between the charges, the individual electric fields are in the same direction and do not cancel. Charge q_2 has a greater magnitude than charge q_1, so a point of zero field must be closer to q_1 than to q_2. It must be to the right of q_1 on the diagram.



We put the origin at q_2 and let x be the coordinate of P, the point where the field vanishes. Then, the total electric field at P is given by

$$E = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2}{x^2} - \frac{q_1}{(x-d)^2}\right)$$

where q_1 and q_2 are the magnitudes of the charges. If the field is to vanish,

$$\frac{q_2}{x^2} = \frac{q_1}{(x-d)^2} \; .$$

We take the square root of both sides to obtain $\sqrt{q_2}/x = \sqrt{q_1}/(x-d)$. The solution for x is

$$\begin{aligned} x &= \left(\frac{\sqrt{q_2}}{\sqrt{q_2}-\sqrt{q_1}}\right) d \\ &= \left(\frac{\sqrt{4.0 q_1}}{\sqrt{4.0 q_1}-\sqrt{q_1}}\right) d \\ &= \left(\frac{2.0}{2.0-1.0}\right) d = 2.0d \\ &= (2.0)(50\,\text{cm}) = 100 \text{ cm} \; . \end{aligned}$$

The point is 50 cm to the right of q_1.

23. (a) The linear charge density is the charge per unit length of rod. Since the charge is uniformly distributed on the rod, $\lambda = -q/L$.

(b) We position the x axis along the rod with the origin at the left end of the rod, as shown in the diagram. Let dx be an infinitesimal length of rod at x. The charge in this segment is $dq = \lambda\, dx$. The charge dq may be considered to be a point charge. The electric field it produces at point P has only an x component and this component is given by

$$dE_x = \frac{1}{4\pi\varepsilon_0} \frac{\lambda\, dx}{(L + a - x)^2} \, .$$

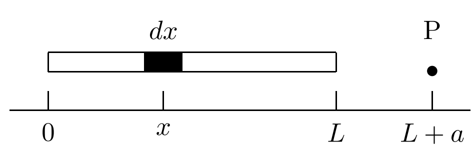
The total electric field produced at P by the whole rod is the integral

$$\begin{aligned} E_x &= \frac{\lambda}{4\pi\varepsilon_0} \int_0^L \frac{dx}{(L+a-x)^2} \\ &= \frac{\lambda}{4\pi\varepsilon_0} \left. \frac{1}{L+a-x} \right|_0^L \\ &= \frac{\lambda}{4\pi\varepsilon_0} \left(\frac{1}{a} - \frac{1}{L+a} \right) \\ &= \frac{\lambda}{4\pi\varepsilon_0} \frac{L}{a(L+a)} \, . \end{aligned}$$

When $-q/L$ is substituted for λ the result is

$$E_x = -\frac{1}{4\pi\varepsilon_0} \frac{q}{a(L+a)} \, .$$

The negative sign indicates that the field is toward the rod.



(c) If a is much larger than L, the quantity $L + a$ in the denominator can be approximated by a and the expression for the electric field becomes

$$E_x = -\frac{q}{4\pi\varepsilon_0 a^2} \, .$$

This is the expression for the electric field of a point charge at the origin.

41. We take the positive direction to be to the right in the figure. The acceleration of the proton is $a_p = eE/m_p$ and the acceleration of the electron is $a_e = -eE/m_e$, where E is the magnitude of the electric field, m_p is the mass of the proton, and m_e is the mass of the electron. We take the origin to be at the initial position of the proton. Then, the coordinate of the proton at time t is $x = \frac{1}{2}a_p t^2$ and the coordinate of the electron is $x = L + \frac{1}{2}a_e t^2$. They pass each other when their coordinates are the same, or $\frac{1}{2}a_p t^2 = L + \frac{1}{2}a_e t^2$. This means $t^2 = 2L/(a_p - a_e)$ and

$$
\begin{aligned}
x &= \frac{a_p}{a_p - a_e}L = \frac{eE/m_p}{(eE/m_p) + (eE/m_e)}L = \frac{m_e}{m_e + m_p}L \\
&= \frac{9.11 \times 10^{-31}\,\text{kg}}{9.11 \times 10^{-31}\,\text{kg} + 1.67 \times 10^{-27}\,\text{kg}}(0.050\,\text{m}) \\
&= 2.7 \times 10^{-5}\ \text{m}\ .
\end{aligned}
$$