

- c) We are to compute the total force acting on the plane by directly integrating over $\sigma^2/2\epsilon_0$.
Let us proceed to compute the force directly:

$$\begin{aligned} F &= \int da \frac{\sigma^2}{2\epsilon_0} = \frac{q^2 d^2}{8\pi^2 \epsilon_0} \int \frac{r dr d\theta}{(r^2 + d^2)^{3/2}}, \\ &= \frac{q^2 d^2}{8\pi^2 \epsilon_0} \int_0^{2\pi} d\theta \int_0^\infty \frac{r dr}{(r^2 + d^2)^{3/2}}, \\ &= -\frac{q^2 d^2}{16\pi \epsilon_0} \frac{1}{u^2} \bigg|_0^\infty, \\ &= -\frac{q^2 d^2}{16\pi \epsilon_0 d^4}. \end{aligned}$$

$$\therefore F = -\frac{q^2}{4\pi \epsilon_0} \frac{1}{(2d)^2} \hat{z}.$$

- d) We are to compute the work required to remove the charge from its position to infinity.
By direct computation, we see that the work required is

$$W = -\int_d^\infty F dz = -\frac{q^2}{16\pi \epsilon_0} \int_d^\infty \frac{dz}{z^2} = \frac{q^2}{16\pi \epsilon_0} \frac{1}{z} \bigg|_d^\infty = \frac{q^2}{16\pi \epsilon_0 d}.$$

- e) Let us compute the potential energy of the charge-image-charge system and compare this result with that of part (d) above.

From the definition of potential energy, we see that

$$U = \frac{q^2}{8\pi \epsilon_0 d}.$$

This is precisely twice the energy required to pull the charge q to infinity. This is important: the energy is twice that of the original system because we also have energy associated with the electric field of the image charge. In the original system, there is only the electric field of a single charge. Furthermore, notice that the position and hence energy of the image charge depends on the charge and position of q . This implies that it is unphysical to consider q moving in a static field produced by q .

- 8.8) Let us consider the problem of a point charge q located inside a hollow, grounded, conducting sphere of inner radius a .

- a) We are to find the potential function describing the inside of the sphere.

This problem is significantly similar to that discussed in Jackson's text regarding a charge located outside a conducting, grounded sphere. It should be clear that if the charge is located at the point \mathbf{r} , then, by total symmetry, the image charge must be located along the direction of \mathbf{r} at a distance of $r' > a$. If the method of image charges applies, therefore, the potential at a point \mathbf{r} will be given by the form

$$\phi(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{|\mathbf{r} - \mathbf{r}|} + \frac{q'}{|\mathbf{r} - \mathbf{r}'|} \right).$$

Because the sphere is grounded, we must have $\phi(r) = 0$ for $r = a$. This situation is identical to that required for the situation described in Jackson and therefore we must have that

$$\frac{1}{a} = -\frac{q'}{q} \quad \text{and} \quad \frac{1}{a} = \frac{r'}{r}.$$

In particular, this implies that

$$\phi(\mathbf{r}) = \frac{q}{4\pi\epsilon_0} \left(\frac{1}{|\mathbf{r} - \mathbf{r}|} + \frac{1}{a} \frac{1}{|\mathbf{r} - \frac{a^2}{r^2} \mathbf{r}|} \right).$$

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